MESSE MÜNCHEN INTERNATIONAL

17th International Conference
on Photonics in Europe

Co-located with LASER 2005, World of Photonics

World OF Photonics Congress 2005

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Technical Programme

Optical Metrology

Optical Measurement Systems for Industrial Inspection

Optical Methods for Arts and Archaeology

Micro- and Nano-Metrology

June 12–16, 2005

Munich ICM
International Congress Centre Munich

SPIE *Europe*

SPIE International Symposium

Optical Metrology

13–17 June 2005
ICM—International Conference Centre Munich
Munich, Germany

The International Symposium on Optical Metrology is the only conference in Europe to bring together scientists, engineers, researchers, and applications or product developers engaged in optical metrology, art conservation, and multimedia. Co-located with Laser 2005, World of Photonics in Munich, Germany, this symposium will address the role of lasers in the following areas:

Optical Measurement Systems for Industrial Inspection IV

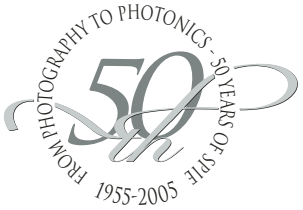
Optical Methods for Arts and Archaeology

Nano- and Micro-Metrology

We invite all those involved in related industries to join their colleagues and share results related to the conference topics at next year's symposium.

Werner Jüptner,
Bremer Institut für Angewandte Strahltechnik (Germany)

Ralph P. Tatam,
Cranfield Univ. (United Kingdom)



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SPIE—The International Society for Optical Engineering is dedicated to advancing scientific research and engineering applications of optical, photonic, imaging, and optoelectronic technologies through its meetings, education programs, and publications.

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Coinciding with the 100th anniversary of Albert Einstein's "Miraculous Year," the events of the World Year of Physics 2005 aim to raise worldwide public awareness for physics and more generally for physical sciences.

SPIE would like to express its deepest appreciation to the symposium and conference chairs and cochairs, and programme committee members who have so generously given of their time and advice to make this symposium possible. The symposium, like our other conferences and activities, would not be possible without the dedicated contribution of our participants and members.

This Programme is based on commitments received up to the time of publication and is subject to change without notice.

SPIE's Project Manager for this symposium is Karin Burger. For information about the technical programme, email: meetinginfo@spie.org.

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SPIE Plenary Session

ICM: Room 1 . . . . . Wednesday 10.30 to 11.20

Dedicated near-field microscopies for electronic materials and devices

L. J. Balk, Univ. Wuppertal (Germany)

Coauthors: **R. Heiderhoff,** Univ. Wuppertal (Germany); **J. C. H. Phang,** National Univ. of Singapore (Singapore); **O. V. Sergeev,** Belarusian State Univ. of Informatics and Radioele (Belarus)

With the ongoing reduction of structures sizes within any kind of electronic device inspection tools have to be used allowing a resolution of clearly below 50nm. This is not only necessary for a mere topological evaluation of the material or the device under test, but even more important for the nanoscopic determination of material parameters and device properties.

When using waves as probes for this purpose, near-field techniques are quite often the only means for overcoming the limitation in spatial resolution as due to Rayleigh's criterion, independently of the specific nature of the wave type used. In this manner acoustical and thermal waves can be applied for very high resolution testing as well as the well known scanning near-field optical microscope.
Moreover, such techniques are not limited to such simple systems, in which the probing wave and the resulting interaction product are of same nature, like often in near-field optical microscopy, but more complicated systems may be suitable to gain the information needed.

In this sense near-field optical microscopy can be used for optical induced current measurements as well as for nanoscopic cathodoluminescence experiments, the evaluation of ferroelectric domains by polarization evaluation and the analysis of integrated silicon circuits by near-field photon emission microscopy are possible, too.

To achieve a more comprehensive information on the sample, results gained with one special technique can be compared with others, such as scanning thermal or acoustic microscopy. These allow determination of mechanical and thermal properties with the appropriate spatial resolution that can be compared - quite often simultaneously - with, for instance, optical and optoelectronic structures.

The necessary instrumentation will be described for those experiments with emphasis on the scanning near-field optical microscope. Examples for the application of near-field microscopies will be given for silicon technology as well as for compound semiconductors and functional ferroelectric ceramics. Usual electronic components like solar cells or light emitting devices will be treated as well as micro electro mechanical systems.

Biography: **Ludwig Josef Balk** received his diploma as physicist from the RWTH Aachen in 1971. In 1991 he became full professor for electronics at the Bergische Universitaet Wuppertal. His research is the development, improvement, and application of instrumentation for the analysis of materials and the diagnostics of devices. He has over 200 publications, of which over 50 are invited papers, and has given more than 100 invited seminar talks world wide. In 1999 he became Fellow of the Institute of Physics, U.K..

Special Events

Reception

Monday . . . . . 19.00 to 21.00

This evening event will feature a light meal and beverages at one of Munich's premier breweries, the Paulaner Bräuhaus. All registered conference attendees are welcome. A guest may accompany a registered attendee for an additional charge (space available).

Directions from International Convention Center

By public transportation: Take local train to Marienplatz, then change into U3/U6 in direction of Fuerstenried West or Klinikum Grosshadern, get off at stop "Goetheplatz" - from there walk through Haeberlstrasse; 2 mins on foot.

By car: Go towards city centre, railway station, middle ring, Sendlinger-Tor-Platz, Lindwurmstrasse to Goetheplatz, turn left into Haeberlstrasse (straight across from the employment office)

Posters

Tuesday-Thursday

See conference listings for details.

Posters will be on display on the second floor foyer next to the WLAN Hotspot; e-posters will be displayed in the ICM internet café. Poster authors, please look for the poster presentation details and poster session schedule for each conference in the EOM05 conference programmes. Any papers left on the boards at the close of each conference poster session will be considered as unwanted and will be discarded. Poster authors should be at their papers during each conference poster session to answer questions from attendees.

Registration

ICM Entry Lobby

Sunday ..... 13:00 to 17:00
Monday through Thursday ..... 8:00 to 17:00
Friday ..... 8:00 to 10:30

Coffee Breaks

Ground Level Foyer

Monday ..... 16:00 to 16:30
Tuesday ..... 10:30-11:00 and 15:30 to 16:00
Wednesday-Friday ..... 10:30-11:00 and 16:00 to 16:30

Coffee will be served in the Ground Level Foyer from 10.00 to 10.30, and 16.00 to 16.30 each day and 15:30-16:00 on Wednesday.

Poster Session

Posters will be on display on the second floor foyer next to the WLAN Hotspot; e-posters will be displayed in the ICM Internet Café. Poster authors please look for the poster session schedule for each conference in the EOM05 conference programmes. Any posters left on the boards at the close of each conference poster session will be considered as unwanted and will be discarded. Poster authors should be at their papers during each conference poster session to answer questions from attendees.

SPIE Plenary Session

Room 1

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Great location in the city, near Hauptbanhof station and on the direct Ubahnline to the Messe.

Großer Rosengarten
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Situated in the heart of the city center of Munich, 1 minute away from the central railway station.

Hotel Ludwig
Tel: 49 (0) 89 551390; Fax: 49 (0) 89 593403
Hotel offers 139 rooms and suites in a modern and comfortable style.

Transportation from Airport to City Centre

The Franz Josef Strauss Airport (MUC) is located 17 miles (27 km) northeast of the center of Munich, http://www.munich-airport.de/en/

Please refer to the Munich International Airport web site for detailed information on transportation, departures and arrivals, and Munich timetables:

Taxi: Taxis are available outside the airport terminal. The cost is high, approximately €40, and the trip will take 30 to 45 minutes to the Center of Munich.

Train: The Airport Rapid Transit Trains leave for the center of Munich frequently. Stations Marienplatz and Hauptbahnhof (central rail station) are the stops in the center. The trip will take 3040 minutes and the cost is approximately €8. Follow the signs as you leave the customs area.

Bus: During the international trade fair, a special Trade Fair Shuttle Bus Service operates between the Munich Airport and the ICM. The buses run at 30-minute intervals nonstop from the airport to the trade fair grounds. This service is free of charge upon presentation of a valid trade fair admission ticket, which can be obtained either at the trade fair information counter in the central area of the Munich airport or on the bus. Otherwise, the fair is approximately €8 for a single and €13 for a return journey. The journey takes about 35 minutes, depending on volumes of traffic.

Transportation from Munich City Centre to ICM—International Congress Center Munich

The ICM is about 30-45 minutes from downtown Munich.

Free public transport: All registered conference attendees are eligible to use all Munich City Transport (MW- urban railway, underground, trams, and buses) and Laser Airport shuttle by presenting a corresponding ticket together with a conference entrance pass. Passes will be provided onsite with registration.

For the most current information about all transport options, schedules, and prices, please visit: Munich Airport, http://www.munich-airport.de/en/

About Munich

Munich, "the city with a heart", is the capital of Bavaria, and has established itself as Germany's high tech hub (Silicon Bavaria) and as one of the most important industrial and economic centers in the European community. It boasts such high tech corporations as BMW and DaimlerChrysler Aerospace. In addition to being the country's leading university center and hub for insurance, banking, electronic and mechanical engineering, Munich offers its visitors shopping, music, art, gourmet restaurants, beer gardens, outdoor cafes, ethnic restaurants, popular nightspots, grand cathedrals, and opulent palaces.

For more information on Munich and the surrounding area, please refer to the following Web sites:

- Munich Tourist Office: http://www.muenchen-tourist.de/
- Munichfound: http://www.munichfound.de/
- Munich Travel from tyzo.com: http://www.tyzo.com/europe/germany/munich/

Optical Metrology
13–17 June 2005
Munich, Germany

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Optical Measurement Systems for Industrial Inspection IV

Conference Chair: **Wolfgang Osten**, Univ. Stuttgart (Germany)

Cochairs: **Christophe Gorecki**, Univ. de Franche-Comté (France); **Erik Novak**, Veeco Instruments Inc. (USA)

Programme Committee: **Armando Albertazzi, Jr.**, Univ. Federal de Santa Catarina (Brazil); **Anand K. Asundi**, Nanyang Technological Univ. (Singapore); **Yuri V. Chugui**, Technological Design Inst. Scientific Instr. Engg. (Russia); **Peter J. de Groot**, Zygo Corp. (USA); **Zoltán Füzessy**, Budapest Univ. of Technology and Economics (Hungary); **Steen G. Hanson**, Risoe National Lab. (Denmark); **Gerd Häusler**, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); **Roland Höfling**, ViALUX GmbH (Germany); **Pierre M. Jacquot**, Ecole Polytechnic Federale de Lausanne (Switzerland); **Gerd Jäger**, Technische Univ. Ilmenau (Germany); **Werner P. Jüptner**, Bremer Institut für Angewandte Strahltechnik (Germany); **Richard M. Kowarschik**, Friedrich-Schiller-Univ. Jena (Germany); **Max L. Krieg**, Delft Univ. of Technology (Netherlands); **Malgorzata Kujawinska**, Warsaw Univ. of Technology (Poland); **Vladimir B. Markov**, MetroLaser, Inc. (USA); **Tilo Pfeifer**, RWTH-Aachen (Germany); **Ryszard J. Pryputniewicz**, Worcester Polytechnic Institute (USA); **Rajpal S. Sirohi**, Indian Institute of Technology (India); **Hans Steinbichler**, Steinbichler Optotechnik GmbH (Germany); **Mitsuo Takeda**, Univ. of Electro-Communications (Japan); **Ralph P. Tatam**, Cranfield Univ. (United Kingdom); **Hans J. Tiziani**, Univ. Stuttgart (Germany); **Theo T. Tschudi**, Technische Univ. Darmstadt (Germany); **Elmar E. Wagner**, Fraunhofer Gesellschaft (Germany); **Ichirou Yamaguchi**, Gunma Univ. (Japan); **Toyohiko Yatagai**, Univ. of Tsukuba (Japan)

Monday 13 June

Welcome and Introduction ..... 14.00 to 14.10
Wolfgang Osten, Univ. Stuttgart (Germany)

SESSION 1

Room: 14c ..... Mon. 14.10 to 16.00

New Approaches: Algorithms I

Chair: **Wolfgang Osten**, Univ. Stuttgart (Germany)

14.10: **Modern approaches in phase measuring metrology *(Invited Paper),*** J. C. Wyant, The Univ. of Arizona (USA) ..... [5856-01]

14.40: **Full-field low-frequency heterodyne interferometry using CMOS and CCD cameras with online phase processing,** F. Lakestani, M. P. Whelan, European Joint Research Ctr. (Italy); J. Garvey, D. Newport, Univ. of Limerick (Ireland) .. [5856-02]

15.00: **Fast three-dimensional phase-unwrapping algorithm based on sorting by reliability following a non-continuous path,** H. S. Abdul-Rahman, M. A. Gdeisat, D. R. Burton, Liverpool John Moores Univ. (United Kingdom); M. J. Lalor, Liverpool John Moores Univ. (USA) ..... [5856-03]

15.20: **Gated heterodyne coherent anti-Stokes Raman scattering for high-contrast vibrational imaging,** M. Greve, B. Bodermann, H. R. Telle, Physikalisch-Technische Bundesanstalt (Germany); P. Baum, E. Riedle, Ludwig-Maximilians-Univ. München (Germany) ..... [5856-04]

15.40: **Study of polarizing intercorrelative function of coherent images of phase-inhomogeneous layer anisotropy,** O. V. Angelsky, A. G. Ushenko, I. M. Vashenko, L. M. Bodnar, Yuriy Fedkovych Chernivtsi National Univ. (Ukraine) ..... [5856-05]

Coffee Break ..... 16.00 to 16.20

SESSION 2

Room: 14c ..... Mon. 16.20 to 18.00

New Approaches: Algorithms II

Chair: **Mitsuo Takeda**, The Univ. of Electro-Communications (Japan)

16.20: **Comparison of B-Spline and Zernike fitting techniques in complex wavefront surfaces,** S. Royo, C. Pizarro, M. Ares, Univ. Politècnica de Catalunya (Spain) ..... [5856-76]

16.40: **Reconstruction of in-line hologram using iterative algorithm,** Y. Zhang, Capital Normal Univ. (China) ..... [5856-07]

17.00: **Image focusing properties in reconstructing digital holograms,** P. Ferraro, S. Grilli, D. Alfieri, Istituto Nazionale di Ottica Applicata (Italy); G. Coppola, V. Striano, Istituto per la Microelettronica e Microsistemi (Italy); S. DeNicola, A. Finizio, G. Pierattini, Istituto di Cibernetica (Italy) ..... [5856-08]

17.20: **High-resolution lensless Fourier-transform digital holography,** I. Banyasz, Research Institute for Solid-state Physics and Optics (Hungary); J. Kornis, Budapest Univ. of Technology and Economics (Hungary) ..... [5856-09]

17.40: **Determination and applications of contoured windows for ESPI fringe pattern processing,** Q. Yu, X. Yang, S. Fu, X. Sun, National Univ. of Defense Technology (China) ..... [5856-10]

Tuesday 14 June

SESSION 3

Room: 14c ..... Tues. 08.20 to 10.00

Displacement and Strain Measurement: Static Displacements

Chair: **Petra Aswendt**, Fraunhofer Institute (Germany)

08.20: **Recent issues on development of reference materials and standarized tests of optical methods of strain measurement,** R. Burguete, Airbus UK (United Kingdom); E. K. Hack, EMPA (Switzerland); M. Kujawinska, Warsaw Univ. of Technology (Poland); E. A. Patterson, The Univ. of Sheffield (United Kingdom); L. A. Salbut, Politechnika Wroclawska (Poland); T. Siebert, Dantec Ettemeyer GmbH (Germany); M. P. Whelan, European Commission (Italy) ..... [5856-48]

08.40: **Polarization plane rotator used as a phase stepping device in a 2-channel shearing speckle interferometer,** P. A. Somers, N. Bhattacharya, Technische Univ. Delft (Netherlands) ..... [5856-49]

09.00: **TV-holographic mapping of airborne sound fields for the design of parametric arrays,** K. D. Hinsch, H. Joost, G. Guelker, Carl von Ossietzky Univ. Oldenburg (Germany) ..... [5856-50]

09.20: **Comparison of shearography and optical fibre Bragg grating strain sensors with resistance foil strain gauge measurements,** R. M. Groves, E. Chehura, Cranfield Univ. (United Kingdom); W. Li, Wuhan Univ. of Technology (China); S. E. Staines, S. W. James, R. P. Tatam, Cranfield Univ. (United Kingdom) ..... [5856-51]

09.40: **Fast distance sensing by use of the speckle effect,** E. Nippolainen, D. V. Semenov, A. A. Kamshilin, Univ. of Kuopio (Finland); A. V. Belyaev, S. V. Andreev, B. S. Gurevich, Scientific Devices Ltd. (Russia) ..... [5856-52]

Coffee Break ..... 10.00 to 10.30

SESSION 4

Room: 14c ..... Tues. 10.30 to 12.30

Displacement and Strain Measurement: Dynamic Displacements

Chair: **Armando Albertazzi Gonçalves, Jr.**, Univ. Federal de Santa Catarina (Brazil)

10.30: **The laser-scanning confocal vibrometer microscope,** C. Rembe, A. Dräbenstedt, Polytec GmbH (Germany) ..... [5856-53]

10.50: **Accuracy analysis of major signal processing techniques in laser Doppler velocimetry,** I. A. Popov, George Kelk Corp. (Canada) ..... [5856-54]

11.10: **Phase shifting aided time average interferometry for vibration investigation: modulation determination error analysis,** K. Patorski, A. R. Styk, Warsaw Univ. of Technology (Poland) ..... [5856-55]

11.30: **Development and investigation of high-resolution resonant pressure sensor with optical interrogation,** M. Jozwik, C. Gorecki, A. Sabac, Univ. de Franche-Comté (France); A. Jacobelli, T. Dean, Thales Research & Technology France (France) ..... [5856-56]

11.50: **Time synchronization of oscillating objects with laser pulse in interferometry,** J. Bartold, Warsaw Univ. of Technology (Poland) ..... [5856-57]

12.10: **Specification of vibrational modes and amplitudes in large-scale structure by time averaging moiré technique,** S. Rasouli, Institute for Advanced Studies in Basic Sciences (Iran); M. T. Tavassoly, Institute for Advanced Studies in Basic Sciences (Iran) and Tehran Univ. (Iran) ..... [5856-58]

Lunch Break ..... 12.30 to 13.40

✔ Posters-Tuesday

Poster Pops (3 minute oral presentations in the conference room) 1:40 to 18:00 hrs

Coffee Break . . . . . 15.30 to 16.00 hrs

Posters will be on display 9.00 to 18.00 hrs Tuesday on the second floor foyer next to the WLAN Hotspot. Any papers left on the boards at the close of the poster session will be considered as unwanted and will be discarded. E-posters will be displayed in the ICM internet café.

New Approaches

✔ **Novel real-time infrared image processor with ADSP,** C. Ge, G. Fan, Institute of Applied Electronics (China) . . . . . [5856-77]

✔ **New approach for simple and rapid shape measurement of objects with surface discontinuities,** S. S. Gorthi, K. R. Lolla, Indian Institute of Science (India) . . . . . [5856-78]

✔ **Polarizing-correlative processing of images of statistical objects in the problem of visualization and topology reconstruction of their phase heterogeneity,** O. V. Angelsky, A. G. Ushenko, I. V. Vashenko, L. M. Bodnar, Yuriy Fedkovych Chernivtsi National Univ. (Ukraine) . . . . . [5856-79]

✔ **Grid pattern design for fast scene reconstruction by a 3D vision sensor,** Q. Guan, S. Chen, Zhejiang Univ. of Technology (China) . . . . . [5856-80]

✔ **Focusing action of refractive microloens by rigorous method,** J. Liu, Beijing Jiaotong Univ. (China); B. Gu, Chinese Academy of Sciences (China); B. Dong, G. Yang, Institute of Physics (China) . . . . . [5856-81]

✔ **Automatic tracing of interference fringes using Fourier filtering, local thresholding and simultaneous horizontal and vertical scans,** A. Anand, Institute for Plasma Research (India); V. K. Chhaniwal, M.S. Univ. of Baroda (India) . . . . . [5856-82]

✔ **Application of matched digital filters to noisy fringe-patterns from complex wavefronts,** J. Caum, J. Arasa, S. Royo, M. Ares, Univ. Politècnica de Catalunya (Spain) . . . . . [5856-83]

✔ **Focus sensor for an application in a nanopositioning and nanomeasuring machine,** R. Mastylo, D. Dontsov, E. Manske, G. Jäger, Technische Univ. Ilmenau (Germany) . . . . . [5856-84]

✔ **Application of super image methods in digital holography,** J. Kornis, B. Gombkötö, Budapest Univ. of Technology and Economics (Hungary) . [5856-85]

✔ **Phase evaluation using interference of polychromatic light and colorimetric analysis,** P. Novák, J. Novák, A. Mik‰, Czech Technical Univ. in Prague (Czech Republic) . . . . . [5856-86]

✔ **Wavelet transform analysis of truncated fringe patterns in 3D surface profilometry,** S. S. Gorthi, K. R. Lolla, Indian Institute of Science (India) [5856-87]

✔ **Evaluation of spectral modulated interferograms by the extended Kalman filtering method,** I. P. Gurov, St. Petersburg Institute of Fine Mechanics and Optics (Russia); P. Hlubina, Technical Univ. of Ostrava (Czech Republic); M. Taratin, A. V. Zakharov, St. Petersburg Institute of Fine Mechanics and Optics (Russia) . . . . . [5856-88]

✔ **A compact frequency-stabilized Nd:YVO4/KTP/I2 laser at 532 nm for laser interferometry and wavelength standards,** L. F. Vitushkin, Bureau International des Poids et Mesures (France); O. A. Orlov, D.I. Mendeleyev Institute for Metrology (Russia) . . . . . [5856-89]

✔ **An objective measure of the quality of honed surfaces (stand-by oral presentation),** F. Puente Leon, Technische Univ. München (Germany) [5856-90]

✔ **Revolution in video microscopy and measurement,** E. Leonhardt, Flokal (Netherlands) . . . . . [5856-91]

Shape Measurement

✔ **Wavefront reconstruction with the adaptive Shack-Hartmann sensor (stand-by oral presentation),** L. Seifert, H. J. Tiziani, W. Osten, Univ. Stuttgart (Germany) . . . . . [5856-93]

✔ **A new approach for measurement of wire diameter by optical diffraction (stand-by oral presentation),** Y. C. Diwan, K. R. Lolla, Indian Institute of Science (India) . . . . . [5856-94]

✔ **Easy calibration of a structured light vision system based on neural networks,** S. Y. Chen, B. Xia, Zhejiang Univ. of Technology (China) . . . . . [5856-95]

✔ **Effectible factors in optics profile testing,** H. Ren, X. Jiang, Z. Huang, H. Xu, W. Zhong, L. Liu, Laser Fusion Research Ctr./CAEP (China) . . . . . [5856-96]

✔ **A compact shearing interferometer for testing optical systems,** J. Novák, P. Novák, A. Mik‰, Czech Technical Univ. in Prague (Czech Republic) . [5856-97]

✔ **500-mm-aperture wavelength-tuning phase-shifting interferometer,** L. Chai, Q. Xu, Fine Optical Engineering Research Ctr. (China); Y. Yu, Shanghai Univ. (China); Y. Deng, Fine Optical Engineering Research Ctr. (China) . . . . . [5856-98]

✔ **Possible application of hyperchromatic optical systems for metrology of surfaces,** J. Novák, A. Mik‰, Czech Technical Univ. in Prague (Czech Republic) . . . . . [5856-100]

✔ **On-line measurements with optical scanners: metrological aspects,** V. Duma, Univ. of Arad (Romania) . . . . . [5856-101]

✔ **Improving 3D surface feature extraction and measurement on metallic surfaces,** R. Kokku, GE Global Research (India); G. W. Brooksby, GE Global research (USA) . . . . . [5856-104]

✔ **Zeeman laser for straightness measurements,** J. Rzepka, G. Budzyn, Politechnika Wroclawska (Poland) and Lasertex Co. Ltd. (Poland); W. Fraczek, M. Bielenin, Lasertex Co. Ltd. (Poland) . . . . . [5856-107]

✔ **How to avoid object caused illumination effects in 3D fringe projection,** P. Kühmstedt, C. Munkelt, M. Heinze, G. Notni, Fraunhofer-Institut für Optik und Feinmechanik (Germany) . . . . . [5856-108]

✔ **Object surface topography by means of a speckle correlation,** P. ·míd, P. Horváth, P. Wagnerova, M. Hrabovsk˘, Palack˘ Univ. (Czech Republic) [5856-109]

✔ **Focal spot measurement in ultra-intense ultra-shot pulse laser facility,** L. Liu, P. H. Sheng, K. Zhou, Laser Fusion Research Ctr./CAEP (China) . . . . . [5856-110]

✔ **Coherent introscopy of phase-inhomogeneous surface and layers,** O. V. Angelsky, A. G. Ushenko, I. V. Vashenko, L. M. Bodnar, Yuriy Fedkovych Chernivtsi National Univ. (Ukraine) . . . . . [5856-111]

Displacement and Strain Measurement

✔ **Phase correlation method for subpixel in-plane vibration measurements of MEMS by stroboscopic microscopy,** B. Serio, J. J. Hunsinger, D. Teyssieux, B. Cretin, Lab. de Physique et Métrologie des Oscillateurs (France) . . . . [5856-113]

Non-Destructive Testing

✔ **Experintal studies of mechanical joints by automated grating (moire) interferometry (stand-by oral presentation),** G. Dymny, Warsaw Univ. of Technology (Poland); D. Boronski, Univ. of Technology and Agriculture (Poland); M. Kujawinska, L. Salbut, Warsaw Univ. of Technology (Poland) . . . . . [5856-114]

✔ **Close infrared thermography using an intensified CCD camera: application in nondestructive high resolution evaluation of electrothermally actuated MEMS,** B. Serio, J. J. Hunsinger, Lab. de Physique et Métrologie des Oscillateurs (France); F. Conseil, P. Derderian, MBDA France (France) . . . . . [5856-117]

✔ **Measurement of beating effects in narrowband multimode Lamb wave displacement fields in aluminum plates by pulsed TV Holography,** J. L. Fernandez, C. Trillo, A. F. Doval, D. Cernadas, C. Lopez, B. V. Dorrio, M. Miranda, F. Rodriguez, Univ. de Vigo (Spain) . . . . . [5856-118]

Applications

✔ **3D optical measuring technologies and systems for industrial inspection,** Y. V. Chugui, Technological Design Institute of Scientific Instrument Engineering (Russia) . . . . . [5856-123]

✔ **Filter radiometer based realization of photometric scale traceable to cryogenic radiometer at UME,** M. Durak, F. Samadov, TUBITAK National Metrology Institute (Turkey) . . . . . [5856-124]

✔ **New method for real-time surface cleanliness measurement,** G. M. Bilmes, D. J. Orzi, Ctr. de Investigaciones Opticas (Argentina) and Univ. Nacional de la Plata (Argentina); O. E. Martinez, Univ. de Buenos Aires (Argentina); A. Lencina, Univ. Federal da Paraíba (Brazil) . . . . . [5856-126]

✔ **Utilizing a TII aspherical measurement machine in a computer controlled polishing process,** E. G. Pitschke, Fachhochschule Deggendorf (Germany) . . . . . [5856-128]

✔ **The evaluation of particle counting efficacy of the new optical scattering method detecting the fluorescence for the particle number concentration standard in liquid,** T. Sakaguchi, K. Ehara, National Institute of Advanced Industrial Science and Technology (Japan) . . . . . [5856-129]

✔ **Seismic Damage Identification using multi-line distributed fiber optic sensor system,** S. Hou, J. Ou, Harbin Institute of Technology (China) . . . . . [5856-131]

✔ **Diffusion coefficient measurement of transparent liquid solutions using digital holographic interferometry,** V. Chhaniwal, M.S. Univ. of Baroda (India); A. Anand, Institute for Plasma Research (India); C. S. Narayanamurthy, M.S. Univ. of Baroda (India) . . . . . [5856-132]

✔ **Pulsed Nd:YAG laser beam profile analyse.,** H. Chmelickova, R. Ctvrtlik, H. Lapsanska, Palack˘ Univ. (Czech Republic) . . . . . [5856-134]

✔ **Birefringence measurement by use of digital holographic microscopy: examples with fiber optics and concrete samples,** T. Colomb, École Polytechnique Fédérale de Lausanne (Switzerland); E. Cuche, Lyncée Tec SA (Switzerland); C. Depeursinge, École Polytechnique Fédérale de Lausanne (Switzerland) . . . . . [5856-138]

✔ **CCD based emissivity measurements for surface characterisation in heat treatment processes,** G. Zauner, Fachhochschule Wels (Austria) . . . . [5856-139]

✔ **Method for measuring the complex refractive index of a turbid medium,** Z. Jian, J. Lin, P. Hsieh, H. Chen, D. Su, National Chiao Tung Univ. (Taiwan) . [5856-140]

Wednesday 15 June

SESSION 5

Room: 14c . . . . . Wed. 08.00 to 10.00

New Approaches: Sensors I

Chair: **Ralph P. Tatam**, Cranfield Univ. (United Kingdom)

08.00: **Reflectivity function based illumination and sensor planning for industrial inspection,** M. M. Ellenrieder, C. Wöhler, P. d'Angelo, Daimler Chrysler AG (Germany) . . . . . [5856-11]

08.20: **Illumination-based segmentation of structured surfaces in automated visual inspection,** C. J. Lindner, J. Arigita López, F. Puente León, Technische Univ. München (Germany) . . . . . [5856-12]

08.40: **New method of structure light measurement system calibration based on adaptive and effective evaluation of 3D-phase distribution,** R. Sitnik, Warsaw Univ. of Technology (Poland) . . . . . [5856-13]

09.00: **Mobile optical 3D sensor for industrial application,** P. Kühmstedt, M. Heinze, M. Himmelreich, G. Notni, Fraunhofer-Institut für Optik und Feinmechanik (Germany) . . . . . [5856-14]

09.20: **Confocal micro-optical distance sensor: principle and design,** A. K. Ruprecht, C. Pruss, H. J. Tiziani, W. Osten, Univ. Stuttgart (Germany); P. Lücke, A. Last, J. Mohr, Forschungszentrum Karlsruhe (Germany); P. H. Lehmann, Mahr GmbH (Germany) . . . . . [5856-15]

09.40: **Confocal microoptical distance sensor: realization and results,** P. Lücke, A. Last, J. Mohr, Forschungszentrum Karlsruhe (Germany); A. K. Ruprecht, C. Pruss, H. J. Tiziani, W. Osten, Univ. Stuttgart (Germany); P. H. Lehmann, Mahr GmbH (Germany) . . . . . [5856-16]

Coffee Break . . . . . 10.00 to 10.30

Room: 1 . . . . . Wed. 10.30 to 11.20

SPIE Plenary Session

10.30: **Dedicated near-field microscopies for electronic materials and devices,** L. J. Balk, R. Heiderhoff, Univ. Wuppertal (Germany); J. C. H. Phang, National Univ. of Singapore (Singapore); O. V. Sergeev, Belarusian State Univ. of Informatics and Radioele (Belarus) . . . . . [5856-200]

SESSION 6

Room: 14c . . . . . Wed. 11.30 to 12.30

New Approaches: Sensors II

Chair: **Petr Hlubina**, Technical Univ. of Ostrava (Czech Republic)

11.30: **Influence of component imperfection on null ellipsometry with phase modulation,** K. Postava, Univ. of Bialystok (Poland) and Technical Univ. of Ostrava (Czech Republic); P. Hlubina, Technical Univ. of Ostrava (Czech Republic); A. Maziewski, Univ. of Bialystok (Poland); M. Foldyna, O. Zivotsky, J. Pistora, Technical Univ. of Ostrava (Czech Republic) . . . . . [5856-17]

11.50: **Compact electronic speckle pattern interferometer (ESPI) system using holographic optical elements (HOEs) and laser diode,** S. R. Guntaka, V. Toal, S. Martin, Dublin Institute of Technology (Ireland) . . . . . [5856-18]

12.10: **Fiber optic spark plug sensor for UV-LIF-measurements close to the ignition spark,** R. Reichle, C. Pruss, W. Osten, H. J. Tiziani, Univ. Stuttgart (Germany); F. Zimmermann, Ruprecht-Karls-Univ. Heidelberg (Germany); C. Schulz, Univ. Duisburg (Germany); J. Wolfrum, Ruprecht-Karls-Univ. Heidelberg (Germany) . . . . . [5856-19]

Lunch Break . . . . . 12.30 to 13.40

SESSION 7

Room: 14c . . . . . Wed. 13.40 to 15.50

Shape Measurement: Shape and Distance I

Chair: **Werner P. Jüptner**, Bremer Institut für Angewandte Strahltechnik (Germany)

13.40: **Optical high-speed 3D metrology in harsh environments: recording structural data of railway lines *(Invited Paper),*** H. Höfler, IPM Fraunhofer Institut für Physikalische Messtechnik (Germany) . . . . . [5856-20]

14.10: **Absolute distance interferometry for space interferometers,** B. L. Swinkels, N. Bhattacharya, Technische Univ. Delft (Netherlands); A. A. Wielders, TNO-TPD (Netherlands); J. J. Braat, Technische Univ. Delft (Netherlands) . . . . . [5856-21]

14.30: **An online laser caliper measurement for the paper industry,** J. S. Graeffe, S. Nuyan, Metso Automation (Finland) . . . . . [5856-22]

14.50: **Robust high-precision 2D optical range sensor,** T. Thurner, M. Brandner, Technische Univ. Graz (Austria) . . . . . [5856-23]

15.10: **Optical distance measurements for closely spaced targets using a FMCW approach,** R. Grosche, Ruhr-Univ. Bochum (Germany) . . . . . [5856-24]

15.30: **Profiling of gas turbine blades using phase shifting Talbot interferometric technique,** C. Shakher, Indian Institute of Technology Delhi (India) and National Institute of Technology Hamirp (India) . . . . . [5856-25]

Coffee Break . . . . . 15.50 to 16.20

SESSION 8

Room: 14c . . . . . Wed. 16.20 to 18.00

Shape Measurement: High-Resolution Metrology

Chair: **Hans J. Tiziani**, Univ. Stuttgart (Germany)

16.20: **Measurements from a novel interferometer for EUVL mirror substrates,** M. L. Krieg, Technische Univ. Delft (Netherlands) . . . . . [5856-26]

16.40: **Improved optical linewidth measurement by means of alternating dark field illumination and model-based evaluation,** G. Ehret, B. Bodermann, W. Mirandé, Physikalisch-Technische Bundesanstalt (Germany) . . . . . [5856-27]

17.00: **Mirror shape detection by "Reflection Moiré Method" with optical design validation,** L. Mercatelli, D. Fontani, P. Sansoni, D. Jafrancesco, F. Francini, Istituto Nazionale di Ottica Applicata (Italy) . . . . . [5856-28]

17.20: **High-accuracy profile form measurement by a scanning system of a slope and coupled distance sensors,** M. Schulz, J. Gerhardt, C. Elster, Physikalisch-Technische Bundesanstalt (Germany) . . . . . [5856-29]

17.40: **Industrial inspection of specular surfaces using a new calibration procedure,** P. Aswendt, Fraunhofer Institute (Germany); R. Höfling, ViALUX GmbH (Germany); S. Gärtner, Max-Planck-Institut für Quantenoptik (Germany) . . . . . [5856-30]

Thursday 16 June

SESSION 9

Room: 14c . . . . . Thurs. 08.10 to 10.00

Shape Measurement: OCT and White-Light IF

Chair: **Alain Bosseboeuf**, Univ. Paris-Sud II (France)

08.10: **High-speed and line-feed Fourier domain optical coherence tomography *(Invited Paper),*** Y. Yasuno, S. Makita, T. Endo, G. Aoki, Univ. of Tsukuba (Japan); J. Sugisaka, Univ of Tsukuba (Japan); Y. Sando, M. Yamanari, M. Itoh, T. Yatagai, Univ. of Tsukuba (Japan) . . . . . [5856-31]

08.40: **2D parallel optical coherence tomography and multiple-layer information extraction,** S. Chang, National Research Council Canada (Canada); X. K. Cai, National Reaserch Council Canada (Canada); E. Murdock, X. Liu, National Research Council Canada (Canada) . . . . . [5856-32]

09.00: **White-light spectral interferometric technique used to measure the dispersion of the group birefringence of a uniaxial crystal,** P. Hlubina, Technical Univ. of Ostrava (Czech Republic) . . . . . [5856-33]

09.20: **Dispersive white-light interferometry for thin-film thickness profile measurement,** S. Kim, Y. Ghim, Korea Advanced Institute of Science and Technology (South Korea) . . . . . [5856-34]

09.40: **Full-field optical coherence topography with a direct Read-out CMOS camera,** P. Egan, Univ. of Limerick (Ireland); F. Lakestani, M. P. Whelan, European Joint Research Ctr. (Italy); M. J. Connelly, Univ. of Limerick (Ireland) . . . . . [5856-35]

Coffee Break . . . . . 10.00 to 10.30

SESSION 10

Room: 14c . . . . . Thurs. 10.30 to 12.10

Shape Measurement: Inspection of Microcomponents

Chair: **Malgorzata Kujawinska**, Warsaw Univ. of Technology (Poland)

10.30: **Micro-optics metrology using advanced interferometry,** S. Reichelt, H. P. Zappe, Albert-Ludwigs-Univ. (Germany) . . . . . [5856-36]

10.50: **Microlenses metrology with digital holographic microscopy,** F. Charrière, J. Kühn, École Polytechnique Fédérale de Lausanne (Switzerland); E. Cuche, Y. Emery, Lyncée Tec SA (Switzerland); K. Weible, SUSS MicroOptics SA (Switzerland); C. D. Depeursinge, École Polytechnique Fédérale de Lausanne (Switzerland) . . [5856-37]

11.10: **Liquid mirror as planarity standard: a simplified experimental approach,** M. Vannoni, G. Molesini, Istituto Nazionale di Ottica Applicata (Italy) . . . . . [5856-92]

11.30: **Development of measurement of micro-structure using moiré topography in SEM.,** Y. Arai, Kansai Univ. (Japan) . . . . . [5856-39]

11.50: **Edge enhancement of week-phase object in laser scanning confocal microscope,** M. Itoh, S. Uematsu, Univ. of Tsukuba (Japan); H. Ishiwata, Olympus Optical Co. Ltd. (Japan); T. Yatagai, Univ. of Tsukuba (Japan) . . . . . [5856-40]

Lunch Break . . . . . 12.10 to 13.40

SESSION 11

Room: 14c ..... Thurs. 13.40 to 16.00

Shape Measurement: Shape and Distance II

Chair: **Max L. Krieg**, Technische Univ. Delft (Netherlands)

13.40: **Dimensional metrology for the fabrication of imaging optics using a high-accuracy low coherence interferometer,** R. C. Wilhelm, A. Courteville, FOGALE nanotech (France) ..... [5856-41]

14.00: **A long standoff profilometer for surface inspection in adverse environments based on conoscopic holography,** J. M. Enguita, I. Alvarez, C. Fraga Bobis, J. Marina, Y. Fernandez, Univ. de Oviedo (Spain); G. Y. Sirat, Optimet Optical Metrology Ltd. (Israel) ..... [5856-42]

14.20: **3D surface reconstruction based on combined analysis of reflectance and polarisation properties,** P. d'Angelo, C. Wöhler, Daimler Chrysler AG (Germany) ..... [5856-43]

14.40: **Computer generated holograms for the optical shop testing of aspheres,** R. Schreiner, JENOPTIK Laser, Optik, Systeme GmbH (Germany) ..... [5856-44]

15.00: **3D measurement of human face by stereogrammetry,** F. Zöllner, H. Wagner, A. Wiegmann, R. M. Kowarschik, Friedrich-Schiller-Univ. Jena (Germany) [5856-45]

15.20: **Precision inspection of diameters for circular reflecting cylinders,** Y. V. Chugui, Y. Lemesko, Technological Design Institute of Scientific Instrument Engineering (Russia) ..... [5856-46]

15.40: **ESPI for contouring of surfaces with discontinuities,** A. Purde, N. Werth, A. W. Koch, Technische Univ. München (Germany) ..... [5856-47]

Coffee Break ..... 16.00 to 16.20

SESSION 12

Room: 14c ..... Thurs. 16.20 to 18.00

Non-Destructive Testing

Chair: **Christoph von Kopylow**, Bremer Institut für Angewandte Strahltechnik (Germany)

16.20: **Performance evaluation of a residual stress measurement device using indentation and a radial in-plance ESPI interferometer,** A. Albertazzi Gonçalves, Jr., R. Sutério, Univ. Federal de Santa Catarina (Brazil) ..... [5856-59]

16.40: **Superconductor ceramics behaviour analyses during service by speckle metrology,** S. Recuero, N. Andrés, P. Arroyo, J. Lobera, L. A. Angurel, F. Lera, Bienvenido a la Univ. de Zaragoza (Spain) ..... [5856-60]

17.00: **Automatic detection of the natural frequencies using digital shearography,** Y. Gan, W. Steinchen, Univ. Kassel (Germany) ..... [5856-61]

17.20: **Experimental comparison of shearography and laser optical feedback imaging for crack detection in concrete structures.,** V. Muzet, LRS-CETE de L'est (France); E. Lacot, O. Hugon, Univ. Joseph Fourier de Grenoble (France); Y. Guillard, LRS-CETE de L'est (France) ..... [5856-62]

17.40: **Interferometric optical tomography applied to dendritic crystal growth model scenes,** J. Dewandel, Lambda-X S.A. (Belgium); S. Rex, ACCESS e.V. (Germany); T. Lanen, Jabberwock B.V. (Netherlands); M. Héraud, Lambda-X S.A. (Belgium); M. Mathes, ACCESS e.V. (Germany); L. Joannes, Lambda-X S.A. (Belgium); J. Becker, European Space Agency (Netherlands) ..... [5856-63]

Friday 17 June

SESSION 13

Room: 14c ..... Fri. 08.20 to 10.00

Applications: Particle and Flow Measurements

Chair: **Yuri V. Chugui**, Technological Design Institute of Scientific Instrument Engineering (Russia)

08.20: **Characterisation of high-density particle distributions for optimisation of laser beam cladding processes using digital holography,** V. Kebbel, J. Geldmacher, K. Partes, W. P. Jüptner, Bremer Institut für Angewandte Strahltechnik (Germany) ..... [5856-71]

08.40: **Laval nozzle flow characterization by Fourier-transform Mach-Zehnder interferometry,** F. Rodriguez, B. V. Dorrio, Á. F. Doval, C. Trillo, F. Quintero, J. Pou, M. Miranda, C. Lopez, J. L. Fernandez, Univ. de Vigo (Spain) ..... [5856-72]

09.00: **Methods based on one component laser Doppler anemometer and hot film anemometer for three-dimensional turbulent measurements,** A. Zeris, P. Prinos, C. Koutitas, Aristotle Univ. of Thessaloniki (Greece) ..... [5856-73]

09.20: **Measurements of material refractive index with a circular heterodyne interferometer,** D. Su, Z. Jian, J. Lin, P. Hsieh, H. Chen, National Chiao Tung Univ. (Taiwan) ..... [5856-74]

09.40: **On-line, non-contact measuring of synchronizer hubs,** C. Fraga Bobis, J. M. Enguita, I. Alvarez, J. Marina, Univ. de Oviedo (Spain); N. Martinez, Sinterstahl Asturias S.A. (Spain) ..... [5856-120]

Coffee Break ..... 10.00 to 10.30

SESSION 14

Room: 14c ..... Fri. 10.30 to 13.00

Applications: Inspection of Microcomponents

Chair: **Christophe Gorecki**, Univ. de Franche-Comté (France)

10.30: **Assessment of technology and (thermo) mechanical behaviour of MEMS devices by interference microscopy *(Invited Paper),*** A. Bosseboeuf, C. Breluzeau, Univ. Paris-Sud II (France); S. Petitgrand, Fogale nanotech (France) .... [5856-64]

11.00: **Laser acoustic characterization of Ta and TaN diffusion barriers beneath Cu layers,** J. Vollmann, D. M. Profunser, J. Bryner, J. Dual, ETH Swiss Federal Institute of Technology Zurich (Switzerland) ..... [5856-65]

11.20: **Thin film measurements by noise in dynamic force microscopy,** P. Vairac, B. Cretin, B. Joly, Lab. de Physique et Métrologie des Oscillateurs (France) [5856-66]

11.40: **Enhancement of image contrast by fluorescence in microtechnology,** M. Berndt, R. Tutsch, Technische Univ. Braunschweig (Germany) ..... [5856-67]

12.00: **Enhancement of high-resolution electronic autocollimators by application of phase grating technology,** G. Fütterer, Physikalisch-Technische Bundesanstalt (Germany) ..... [5856-121]

12.20: **Point-diffraction fiber interferometer for vibration desensitization,** J. Park, H. Kihm, S. Kim, Korea Advanced Institute of Science and Technology (South Korea) ..... [5856-69]

12.40: **Digital holography microscopy (DHM): fast and robust systems for industrial inspection with interferometer resolution,** Y. Emery, F. Marquet, E. Cuche, P. Marquet, Lyncée Tec SA (Switzerland); J. Kühn, N. Aspert, M. Botkin, C. D. Depeursinge, École Polytechnique Fédérale de Lausanne (Switzerland) ..[5856-70]

Closing Remarks

Christophe Gorecki, Univ. de Franche-Comté (France)

Optical Methods for Arts and Archaeology

Conference Chairs: **Renzo Salimbeni**, Institute of Applied Physics N. Carrara/CNR (Italy); **Luca Pezzati**, National Institute of Applied Optics/CNR (Italy)

Programme Committee: **John F. Asmus**, Univ. of California/San Diego (USA); **Andreas Burmester**, Doerner Institut (Germany); **Igor P. Gurov**, St. Petersburg Institute of Fine Mechanics and Optics (Russia); **Michel Menu**, Ctr. de Recherche et des Restauration des Musees de France (France); **Yvon L. M. Renotte**, Univ. de Liège (Belgium); **David R. Saunders**, National Gallery (United Kingdom); **Salvatore Siano**, Istituto di Fisica Applicata (Italy)

Monday 13 June

Opening Remarks ..... 09.10 to 09.20

Renzo Salimbeni, Institute of Applied Physics "N. Carrara"/CNR (Italy);
Luca Pezzati, National Institute of Applied Optics/CNR (Italy)

Keynote Session ..... 09.20 to 10.00 am

Keynote

Antimatter, clockwork orange, laser divestment *(Invited Paper)*, **J. F. Asmus, Univ. of California/San Diego (USA) ..... [5857-01]**

Coffee Break ..... 10:00 to 10:30 am

SESSION 1

Room: 4a ..... Mon. 10.30 am to 12.40 pm

Laser Techniques

Chair: **John F. Asmus,** Univ. of California/Sand Diego (USA)

10.30 am: **Laser techniques in conservation in Europe *(Invited Paper)*,** R. Salimbeni, Institute of Applied Physics N. Carrara/CNR (Italy) ..... [5857-02]

11.00 am: **Non-destructive investigation for the assessment of cleaning interventions on pentelic marble surfaces,** A. Moropoulou, E. T. Delegou, National Technical Univ. of Athens (Greece); N. P. Avdelidis, National Technical Univ. of Athens (Greece) and Univ. of Bath (United Kingdom) ..... [5857-03]

11.20 am: **Cleaning and characterisation of objects of cultural value by laser ablation,** G. M. Bilmes, Ctr de Investigaciones Opticas (Argentina) and Univ. de La Plata (Argentina); C. Freisztav, D. Schinca, Ctr de Investigaciones Opticas (Argentina); A. Orsetti, Gobierno de la Ciudad de Buenos Aires (Argentina)[5857-04]

11.40 am: **Optical and thermal confinement in laser cleaning of artworks,** S. Siano, L. Bartoli, F. Grazzi, Istituto di Fisica Applicata Nello Carrara/CNR (Italy) .. [5857-05]

12.00 pm: **Laser dusting of delicate objects,** J. F. Asmus, Univ. of California/San Diego (USA); M. Abraham, Los Angeles County Museum of Art (USA) ... [5857-06]

12.20 pm: **Sulphur selective ablation by UV laser,** V. Nassisi, F. Belloni, G. Buccolieri, G. Caretto, A. Castellano, A. Lorusso, Univ. degli Studi di Lecce (Italy) ..... [5857-40]

Lunch Break ..... 12.40 to 13.40 pm

✔ Posters-Monday

Posters will be on display 9.00 to 18.00 hrs Monday only on the second floor foyer next to the WLAN Hotspot. Any papers left on the boards at the close of the poster session will be considered as unwanted and will be discarded. E-posters will be displayed in the ICM internet café.

Poster authors should be at their papers from 13.40 to 14.20 during the Conference Poster Session to answer questions from attendees.

✔ **Hyperspectral imaging for the recovery of erased and overwritten scripts in old historic manuscripts,** K. E. Rapantzikos, Forth Photonics Hellas SA (Greece); C. Balas, Forth Photonics Hellas SA (Greece) and Technical Univ. of Crete (Greece) ..... [5857-30]

✔ **Novel application of optical coherence tomography for painting diagnostics,** T. F. Arecchi, Univ. degli Studi di Firenze (Italy); M. Bellini, Instituto Nazionale di Ottica Applicata (Italy); C. Corsi, Univ. degli Studi di Firenze (Italy); R. Fontana, M. Materazzi, L. Pezzati, A. Tortora, Instituto Nazionale di Ottica Applicata (Italy) ..... [5857-34]

✔ **Profilometry of medieval Irish stone monuments,** T. P. Daubos, M. R. Redfern, National Univ. of Ireland/Galway (Ireland); D. Ó Cróinín, National Univ. of Ireland/Galway (Ireland) and Foundations of Irish Culture Project (Ireland) ..... [5857-35]

✔ **Application of 3D laser scanning technology in historical building preservation: a case study of a Chinese temple,** Y. M. Chang, N. H. Lu, De Lin Institute of Technology (Taiwan) ..... [5857-36]

✔ **Probabilistic image-based characterization of manuscript inks,** V. Kokla, A. Psarrou, V. Konstantinou, Univ. of Westminster (United Kingdom) .... [5857-38]

✔ **Proposal for an analytical sequence aimed at establishing sutcco's composition and technique used. Study of samples collected in southern Switzerland,** G. Cavallo, Scuola Univ. Professionale della Svizzera Italiana (Switzerland); M. Moresi, Univ. degli Studi di Bari (Italy) ..... [5857-39]

✔ **A fuzzy logic system for Raman spectrum identification,** M. Castanys, Univ. Politècnica de Catalunya (Spain); R. Pérez-Pueyo, UPC (Spain); M. J. Soneira, Univ. Politècnica de Catalunya (Spain) ..... [5857-42]

✔ **Optical characterization of fresh and thermally aged varnish films by spectroscopic ellipsometry for application in Byzantine icon conservation,** K. S. Polikreti, C. Christofidis, Univ. of Cyprus (Cyprus) ..... [5857-43]

✔ **Integrated optical and nuclear microprobe for material analysis,** L. Calcagnile, G. Gianfrate, G. Quarta, L. Maruccio, D. Muscogiuri, Univ. degli Studi di Lecce (Italy) ..... [5857-44]

✔ **Quantitative approach based on IR spectroscopy for a "quality control" of bone samples for AMS radiocarbon dating,** L. Calcagnile, G. Gianfrate, M. D'Elia, G. Quarta, L. Valli, Univ. degli Studi di Lecce (Italy) ..... [5857-45]

SESSION 2

Room: 4a ..... Mon. 14.30 to 17.50 pm

3D Applications

Chair: **Luca Pezzati,** National Institute of Applied Optics/CNR (Italy)

14.30 pm: **NRC's 3D imaging technology for museum and heritage applications *(Invited Paper)*,** J. Taylor, F. Blais, J. Beraldin, G. Godin, L. Borgeat, S. F. El-Hakim, E. Paquet, L. Cournoyer, M. Picard, M. Rioux, National Research Council Canada (Canada); C. Lahanier, Centre de Recherche et de Restauration des Museés de France (France); G. Aitken, Consultant (France) ..... [5857-07]

15.00 pm: **Three-dimensional documentation of 'two dimensional' works of art,** W. Wei, A. de Tagle, I. Hummelen, Netherlands Institute for Cultural Heritage (Netherlands) ..... [5857-08]

15.20 pm: **Interferometric fringes projection system for 3D profilometry and relief investigation,** V. Moreau, B. Tilkens, D. Laboury, Y. L. M. Renotte, Univ. de Liège (Belgium) ..... [5857-09]

15.40 pm: **Realistic realtime illumination of complex environment for immersive systems a case study: the Parthenon,** M. Callieri, CNR/Istituto di Scienza e Tecnologie dell'Informazione (Italy); P. Debevec, J. J. Pair, Univ. of Southern California (USA); R. Scopigno, CNR/Istituto di Scienza e Tecnologie dell'Informazione (Italy) ..... [5857-10]

Coffee Break ..... 16.00 to 16.30 pm

16.30 pm: **An integrated system for measurement of 3D shape and color texture of artistic and architectural cultural assets,** S. Capeleto, M. Fedel, F. Mario, L. Poletto, G. Tondello, N. Brusco, G. M. Cortelazzo, Univ. degli Studi di Padova (Italy) [5857-11]

16.50 pm: **Inspection, 3D modelling and rapid prototyping of cultural heritage by means of a 3D optical digitiser,** G. Sansoni, E. Redaelli, F. Docchio, Univ. degli Studi di Brescia (Italy) ..... [5857-12]

17.10 pm: **3D MADMAC system: optical 3D shape acquisition and processing path for VR application,** R. Sitnik, M. Kujawinska, Warsaw Univ. of Technology (Poland); M. Waglowski, ART@FACTORY (Poland) ..... [5857-13]

17.30 pm: **Optical micro-profilometry for archaeology,** R. Fontana, M. C. Gambino, Instituto Nazionale di Ottica Applicata (Italy); C. Mazzotta, Univ. degli Studi di Lecce (Italy); E. Pampaloni, L. Pezzati, Instituto Nazionale di Ottica Applicata (Italy) ..... [5857-37]

Tuesday 14 June

SESSION 3

Room: 4a ..... Tues. 08.30 to 10.00 am

Spectroscopic Methods

Chair: **Renzo Salimbeni,** Institute of Applied Physics N. Carrara/CNR (Italy)

08.30 am: **Modì: a new mobile double-pulse LIBS instrument for standardless in-situ analysis of cultural heritage *(Invited Paper)*,** G. Cristoforetti, S. Legnaioli, V. Palleschi, L. Pardini, A. Salvetti, E. Tognoni, Istituto per i Processi Chimico-Fisici/CNR (Italy) ..... [5857-15]

09.00 am: **Quantitative elemental analyses of archaeological materials by laser-induced breakdown spectroscopy (LIBS): an overview,** V. Lazic, F. Colao, R. Fantoni, V. Spizzichino, L. Fornarini, ENEA (Italy) ..... [5857-16]

09.20 am: **Spatially resolved pigment identification by reflectance spectroscopy,** P. Boher, C. Thibierge, M. LUET, T. Leroux, ELDIM (France); M. Elias, Univ. Pierre et Marie Curie (France) ..... [5857-18]

09.40 am: **Non-destructive identification of varnishes by UV-fluorescence spectroscopy,** M. Thoury, M. Elias, J. M. Frigerio, Univ. Pierre et Marie Curie (France) ..... [5857-19]

Coffee Break ..... 10.00 to 10.30 am

SESSION 4

Room: 4a . . . . . Tues. 10.30 am to 12.50 pm

Madonna dei Fusi

Chair: **Martin Kemp,** Univ. of Oxford (United Kingdom)

10.30 am: **The Madonna of the Yarwinder: a case study of non-invasive technique for art historians and conservators *(Invited Paper),*** C. Frosinini, R. Bellucci, Opificio delle Pietre Dure e Laboratori di Restauro (Italy) . . . . . [5857-20]

11.10 am: **2D and 3D optical diagnostic techniques applied to "Madonna dei Fusi" by Leonardo da Vinci,** R. Fontana, M. C. Gambino, M. Greco, L. Marras, M. Materazzi, E. Pampaloni, A. Pelagotti, L. Pezzati, P. Poggi, Instituto Nazionale di Ottica Applicata (Italy); C. Sanapo, Instituto Nazionale di Ottica Applicata (Italy) . . . . . [5857-21]

11.30 am: **Fibre optic reflectance spectroscopy and hyper spectral image spectroscopy: two integrated techniques for the study of the "Madonna dei fusi",** A. Casini, M. Bacci, C. Cucci, F. Lotti, M. Picollo, M. Poggesi, Consiglio Nazionale delle Ricerche (Italy); S. Porcinai, Opificio delle Pietre Dure (Italy); B. Radicati, L. Stefani, Consiglio Nazionale delle Ricerche (Italy) . . . . . [5857-22]

11.50 am: **Tools for inverse mapping and visualization of multi-spectral image data on 3D scanned representations of drawings,** M. Callieri, P. Cignoni, F. Ganovelli, P. Pingi, CNR/Istituto di Scienza e Tecnologie dell'Informazione (Italy); F. Ponchio, C. Montani, CNR/Instituto di Scienza e Tecnologie dell'Infomazione (Italy); R. Scopigno, CNR/Istituto di Scienza e Tecnologie dell'Informazione (Italy) . [5857-23]

12.10 pm: **Non-invasive midFTIR characterisation of organic materials in the Madonna dei Fusi by Leonardo da Vinci,** C. Miliani, ISTM/CNR (Italy); B. G. Brunetti, C. Ricci, A. Sgamellotti, Univ. degli Studi di Perugia (Italy) . . . . . [5857-24]

12.30 pm: **Composition and stratigraphy of the paint layers: investigation on the Madonna dei Fusi by ion beam analysis techniques,** N. Grassi, M. E. Fedi, A. Migliori, P. A. Mando, Univ. degli Studi di Firenze (Italy) . . . . . [5857-25]

Lunch Break . . . . . 12.50 to 14.20 pm

SESSION 5

Room: 4a . . . . . Tues. 14.20 to 17.40 pm

Innovative Techniques and Instrumentation

Chair: **David R. Saunders,** National Gallery (United Kingdom)

14.20 pm: **SIRIS: a high-resolution scanning infrared camera for examining paintings *(Invited Paper),*** D. Saunders, N. Atkinson, J. Cupitt, H. Liang, National Gallery (United Kingdom); C. Sawyers, Technology Enterprise (United Kingdom); R. Bingham, Optical Design Service (United Kingdom) . . . . . [5857-27]

14.50 pm: **Atomic force microscopy imaging directly on paper: a study of library materials degradation.,** G. Piantanida, Univ. degli Studi di Roma/La Sapienza (Italy); M. Bicchieri, F. Pinzari, Istituto Centrale per la Patologia del Libro (Italy); C. Coluzza, Univ. degli Studi di Roma/La Sapienza (Italy) . . . . . [5857-28]

15.10 pm: **Optical coatings on glass for preserving artworks from illumination induced damage,** A. M. Piegari, ENEA (Italy); I. Di Sarcina, A. Farini, Instituto Nazionale di Ottica Applicata (Italy) . . . . . [5857-29]

Coffee Break . . . . . 15.30 to 16.00 pm

16.00 pm: **Spectral and colorimetric characterisation of painted surfaces: a scanning device for the imaging analysis of paintings,** P. Carcagnì, A. Della Patria, R. Fontana, M. Greco, M. Mastroianni, M. Materazzi, E. Pampaloni, L. Pezzati, R. Piccolo, Instituto Nazionale di Ottica Applicata (Italy) . . . . . [5857-31]

16.20 pm: **3D-μCT reveals the work processes of cast plaster statues, their internal structures, damages and restorations,** B. J. Illerhaus, Bundesanstalt für Materialforschung und-prüfung (Germany); A. M. Badde, Alte Nationalgalerie Berlin (Germany) . . . . . [5857-14]

16.40 pm: **X-ray computed tomography of an ancient big globe,** F. Casali, M. Bettuzzi, D. Bianconi, R. Brancaccio, S. Cornacchia, Univ. degli Studi di Bologna (Italy) and Istituto Nazionale di Fisica Nucleare (Italy); C. Cucchi, Univ. degli Studi di Bologna (Italy) and IIstituto Nazionale di Fisica Nucleare (Italy); E. Di Nicola, A. Fabbri, Univ. degli Studi di Bologna (Italy); N. Lanconelli, M. P. Morigi, A. Pasini, Univ. degli Studi di Bologna (Italy) and Istituto Nazionale di Fisica Nucleare (Italy); D. Romani, A. Rossi, Univ. degli Studi di Bologna (Italy) . . . . . [5857-32]

17.00 pm: **Optical Coherence Tomography: a non-invasive technique applied to paintings conservation,** H. Liang, National Gallery (United Kingdom); M. Gomez Cid, Univ. of Kent (United Kingdom) and Univ. of Vigo (Spain); R. Cucu, G. Dobre, D. Jackson, Univ. of Kent (United Kingdom); J. Pedro, Ophthalmic Technologies Inc. (Canada); D. Saunders, National Gallery (United Kingdom); A. Podoleanu, Univ. of Kent (United Kingdom) . . . . . [5857-33]

17.20 pm: **Dymamic signal processing and analysis in the OCT system for evaluating multilayer tissues,** I. P. Gurov, St. Petersburg Institute of Fine Mechanics and Opt (Russia); A. Zakharov, St. Petersburg Institute of Fine Mechanics and Optics (Russia); M. Taratin, St. Petersburg Institute of Fine Mechanics and Opt (Russia); M. Bellini, R. Fontana, M. Materazzi, Istituto Nazionale di Ottica Applicata (Italy) . . . . . [5857-26]

Wednesday 15 June

Room: 1 . . . . . Wed. 10.30 to 11.20

SPIE Plenary Session

10.30: **Dedicated near-field microscopies for electronic materials and devices,** L. J. Balk, R. Heiderhoff, Univ. Wuppertal (Germany); J. C. H. Phang, National Univ. of Singapore (Singapore); O. V. Sergeev, Belarusian State Univ. of Informatics and Radioele (Belarus) . . . . . [5856-200]

Nano- and Micro-Metrology

Conference Chairs: **Heidi Ottevaere**, Vrije Univ. Brussel (Belgium); **Peter DeWolf**, Veeco Metrology (France); **Diederik S. Wiersma**, European Lab. for Nonlinear Spectroscopy and INFM (Italy)

Cooperating Organisations

Wednesday 15 June

Room: 1 ..... Wed. 10.30 to 11.20

SPIE Plenary Session

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Thursday 16 June

Opening Remarks ..... 08.00 to 08.05

Heidi Ottevaere, Vrije Univ. Brussel (Belgium)

SESSION 1

Room: B13 ..... Thurs. 08.05 to 10.05

Optical Characterisation of Micro- and Nano-Optical Components

Chair: **Diederik S. Wiersma**, European Lab. for Non-linear Spectroscopy and INFM (Italy)

08.05: **Micro-optics measurement techniques and instrumentation in the European network of excellence on micro-optics (NEMO) *(Invited Paper),*** M. Kujawinska, Warsaw Univ. of Technology (Poland); C. Gorecki, Univ. de Franche-Comté (France); H. Ottevaere, Vrije Univ. Brussel (Belgium); P. Szczepanski, Politechnika Wroclawska (Poland); H. Thienpont, Vrije Univ. Brussel (Belgium) .....[5858-01]

08.35: **International standards for metrology of microlens arrays *(Invited Paper),*** T. Miyashita, Ricoh Co., Ltd. (Japan) ..... [5858-02]

09.05: **Real-time in situ sag characterization of microlenses fabricated with deep lithography with protons,** V. Gomez, H. Ottevaere, H. Thienpont, Vrije Univ. Brussel (Belgium) ..... [5858-03]

09.25: **Interferometric method for measuring the refractive index profile of optical waveguides directly written in glass substrates by femtosecond laser,** P. Ferraro II, L. Aiello, Instituto Nazionale di Ottica Applicata (Italy); S. De Nicola, A. Finizio, Consiglio Nazionale delle Ricerche (Italy); R. Osellame, N. Chiodo, V. Maselli, G. Cerullo, P. Laporta, Politecnico di Milano (Italy) ..... [5858-04]

09.45: **Application of photoelastic tomography to measurement of stress in optical microelements,** P. Kniazewski, T. Kozacki, M. Kujawinska, Warsaw Univ. of Technology (Poland) ..... [5858-05]

Coffee Break ..... 10.05 to 10.35

SESSION 2

Room: B13 ..... Thurs. 10.35 to 12.35

Optical and Interferometric Microscopy

Chair: **Peter DeWolf**, Veeco Metrology (France)

10.35: **Near-field characterization of millimeter long waves guiding structures using a high-accuracy optoelectronic control system holding the sample,** L. Chassagne, S. Topçu, Y. Alayli, P. Juncar, Univ. de Versailles Saint-Quentin-en Yvelines (France); G. Lerondel, S. Blaize, A. Bruyant, I. Stefanon, P. Royer, Univ. de Technologie de Troyes (France) ..... [5858-06]

11.55: **Surface refractive index mapping by use of near-field optical microscopy.,** I. Radko, V. Volkov, S. Bozhevolnyi, Aalborg Univ. (Denmark); J. Henningsen, Dansk Fundamental Metrologi (Denmark); J. Pedersen, Koheras A/S (Denmark) [5858-07]

11.15: **Compact confocal microscopy,** D. Beghuin, Lambda-x SA (Belgium); M. vandeVen, M. Ameloot, Limburgs Univ. Centrum (Belgium); D. Claessens, Verhaert Design and Development nv (Belgium); P. Van Oostveldt, Univ. Gent (Belgium) ..... [5858-08]

11.35: **Comparison of different approaches for modelling microscope images on the basis of rigorous diffraction calculation,** B. Bodermann, G. Ehret, Physikalisch-Technische Bundesanstalt (Germany) ..... [5858-09]

11.55: **Two-dimensional power spectral density measurements of x-ray optics with the micromap interferometric microscope,** V. V. Yashchuk, A. Franck, S. C. Irick, M. R. Howells, A. A. MacDowell, W. R. McKinney, Lawrence Berkeley National Lab. (USA) .....[5858-10]

12.15: **Automated fringe-pattern extrapolation for patterned surface profiling by interference microscopy with Fourier transform analysis,** C. Breluzeau, A. Bosseboeuf, Institut d'Electronique Fondamentale (France); S. Petitgrand, Fogale Nanotech (France); X. Leroux, Institut d'Electronique Fondamentale (France) ..... [5858-11]

Lunch Break ..... 12.35 to 13.35

✔ Posters-Thursday

Posters will be on display 9.00 to 18.00 hrs Thursday on the second floor foyer next to the WLAN Hotspot. Any papers left on the boards at the close of the poster session will be considered as unwanted and will be discarded. E-posters will be displayed in the ICM internet café.

Poster authors should be at their papers from 13.35 to 14.05 during the Conference Poster Session to answer questions from attendees.

✔ **Manufacturing and testing of x-ray imaging components with high precision,** J. Hu, Dalian Univ. of Technology (China) and Changchun Institute of Optics, Fine Mechanics and Physics (China) and Univ. of California/Santa Barbara (USA); Y. Bai, Changchun Institute of Optics, Fine Mechanics and Physics (China) ..... [5858-29]

✔ **Displacement metrology based on grating imaging with a cylindrical lens array and a phase grating,** T. Oka, Mitsubishi Electric Corp. (Japan); Y. Ohmura, T. Nakashima, Mitsubishi Electric Corp. (Japan); W. Gao, K. Hane, S. Kiyono, Tohoku Univ. (Japan) ..... [5858-30]

✔ **High-accuracy reflectometry technique and statistic measurements treatment method for refraction index determination,** M. G. García Granda, D. F. Pozo Ayuso, S. Fernández Fernández, Univ. de Oviedo (Spain); J. Rodriguez García, Univ. of Oviedo (Spain) .....[5858-31]

✔ **Two methods to determination topological charge in regular net of optical vortices.,** E. Fraczek, W. Fraczek, Wroclaw Univ. of Technology (Poland) [5858-32]

✔ **Optimum instrumentation of a tapping mode, non-optically regulated near-field scanning optical microscope and its applications,** N. H. Lu, De Lin Institute of Technology (Taiwan) and National Taiwan Univ. (Taiwan); Y. M. Chang, De Lin Institute of Technology (Taiwan); D. P. Tsai, National Taiwan Univ. (Taiwan) ..... [5858-33]

✔ **Elimination of 'ghost'-effect-related systematics in the x-ray optics metrology with long trace profiler,** V. V. Yashchuk, S. C. Irick, A. A. MacDowell, Lawrence Berkeley National Lab. (USA) ..... [5858-34]

✔ **Airy-like internal reflection series applied in scatterometry and simulations of gratings,** R. Antos, J. Mistrik, T. Yamaguchi, Shizuoka Univ. (Japan); M. Horie, Dainppon Screen Mfg. Co. (Japan); S. Visnovsky, Charles Univ. (Czech Republic) ..... [5858-35]

✔ **A novel cavity control technique for the stabilization of a burst, pulsed laser,** F. Trespidi, E. Stucchi, E. Nava, CESI (Italy) ..... [5858-36]

✔ **Comparison of methods for the determinaion of the apertur correction of interference microscopes,** R. Krueger-Sehm, Physikalisch-Technische Bundesanstalt (Germany) .....[5858-37]

✔ **Biological specimens analysis using dynamic speckle spectral bands,** M. Trivi, R. Arizaga, H. Rabal, Univ. Nacional de la Plata (Argentina) and Univ. Nacional de Mar del Plata (Argentina); G. Sendra, Univ. Nacional de Mar del Plata (Argentina) ..... [5858-38]

✔ **A VDI-guideline for the calibration of interference microscopes - presentation and practical use,** R. Krueger-Sehm, Physikalisch-Technische Bundesanstalt (Germany) ..... [5858-39]

✔ **Investigation and evaluation of scatterometric CD metrology methods,** M. Wurm, B. Bodermann, W. Mirandé, Physikalisch-Technische Bundesanstalt (Germany) [5858-40]

✔ **Analytical model of a double grating system with partial temporal and spatial coherence,** L. M. Sanchez-Brea, J. Alonso, Univ. Complutense de Madrid (Spain); J. B. Saez-Landete, Univ. de Alcala (Spain); E. Bernabeu, Univ. Complutense de Madrid (Spain) . . . . . [5858-41]

✔ **Non-destructive optical system based on digital holographic microscope for quasi real-time characterisation of a micromechanical shunt switch,** G. Coppola, V. Striano, Consiglio Nazionale delle Ricerche (Italy); P. Ferraro, D. Alfieri, Instituto Nazionale di Ottica Applicata (Italy); S. De Nicola, A. finizio, R. Marcelli, Consiglio Nazionale delle Ricerche (Italy); B. Margesin, F. Giacomozzi, Istituto Trentino di Cultura (Italy); G. Pierattini, Consiglio Nazionale delle Ricerche (Italy) [5858-42]

✔ **Uncertainty analysis for phase measurement on PSM with a 193nm common-path shearing interferometer,** G. Fuetterer, Physikalisch-Technische Bundesanstalt (Germany); J. Schwider, Friedrich-Alexander-Univ. Erlangen-Nürnburg (Germany) . . . . . [5858-43]

✔ **New imaging method using dynamic digital birefringence in nano particles and nano structure patterning calibration,** S. Liu, Oxford Cryosystems Ltd (United Kingdom) . . . . . [5858-44]

✔ **Mueller polarimetry in conical diffraction for CD measurements in microelectronics,** T. A. Novikova, A. De Martino, S. B. Hatit, B. Drévillon, École Polytechnique (France); D. Cattelan, HORIBA Jobin Yvon (France) . . . . [5858-45]

✔ **Effect of the refraction index in the diameter estimation of thin metallic wires,** L. M. Sanchez-Brea, J. C. Martinez-Anton, E. Bernabeu, Univ. Complutense de Madrid (Spain) . . . . . [5858-46]

SESSION 3

Room: B13 . . . . . Thurs. 14.10 to 16.10

Scatterometry, Ellipsometry, and Polarimetry

Chair: **Hugo Thienpont**, Vrije Univ. Brussel (Belgium)

14.10: **Influence of the real-life structures in optical metrology using spectroscopic scatterometry analysis,** R. Quintanilha, CEA/LETI (France) and STMicroelectronics (French Polynesia); P. Thony, CEA/LETI (France) and STMicroelectronics (France); D. Henry, STMicroelectronics (France); J. Hazart, CEA/LETI (France) . . . . . [5858-12]

14.30: **Comparative CD-SEM and scatterometry study of intra-wafer and intra-exposure field CD uniformity for process control of GC stack,** M. Moert II, W. Koestler, M. Rössiger, T. Hingst, P. Reinig, H. Sachse, Infineon Technologies (Germany) . . . . . [5858-13]

14.50: **Extending conventional scatterometry using generalized ellipsometry,** T. Geiler, P. Reinig, M. Moert, T. Hingst, U. Mantz, Infineon Technologies (Germany); J. Renger, L. M. Eng, Technische Univ. Dresden (Germany) . . . . . [5858-14]

15.10: **Determination of the optical properties of thin absorbing layers with spectroscopic ellipsometry and interferometric microscopy,** A. T. Kudla, L. Borowicz, Instytut Technologii Elektronowej (Poland) . . . . . [5858-15]

15.30: **Stress and morphological stability of ultra-thin nickel silicide and nickel germanosilicide films probed by micro-Raman spectroscopy,** H. Yao, S. Tripathy, D. Chi, S. Chua, Institute of Materials Research and Engineering (Singapore) [5858-16]

15.50: **Polarimetry: measurements, errors analysis and applications,** C. Flueraru, National Research Council Canada (Canada) . . . . . [5858-17]

Coffee Break . . . . . 16.10 to 16.40

SESSION 4

Room: B13 . . . . . Thurs. 16.40 to 17.40

Principles and Applications of Optical Tomography

Chair: **Malgorzata Kujawinska**, Warsaw Univ. of Technology (Poland)

16.40: **Optical coherence tomography with a Fizeau interferometer configuration,** P. Casaubieilh, H. D. Ford, R. P. Tatam, Cranfield Univ. (United Kingdom) . . [5858-18]

17.00: **Full-field optical coherence tomography,** H. D. Ford, R. P. Tatam, Cranfield Univ. (United Kingdom) . . . . . [5858-19]

17.20: **Optimisation of low-coherence speckle interferometry (LCSI) for charcterisation of multi-layered materials,** K. Gastinger, SINTEF ICT (Norway); K. D. Hinsch, Carl von Ossietzky Universität Oldenburg (Germany); S. Winther, SINTEF ICT (Norway) . . . . . [5858-20]

Friday 17 June

SESSION 5

Room: B13 . . . . . Fri. 08.30 to 10.00

Optical Interferometry I

Chair: **Takaaki Miyashita**, Ricoh Co., Ltd. (Japan)

08.30: **Portable interference device for roughness measurement *(Invited Paper),*** O. V. Angelsky, P. P. Maksimyak, Chernivtsi National Univ. (Ukraine) . . . . . [5858-21]

09.00: **Sub-0.1μm track width measurement using a common path optical interferometer and artificial neural network.,** R. J. Smith, C. W. See, M. G. Somekh, Univ. of Nottingham (United Kingdom); A. Yacoot, National Physical Lab. (United Kingdom) . . . . . [5858-22]

09.20: **Absolute distance measurment using femtosecond pulse lasers,** S. Kim, K. Joo, Korea Advanced Institute of Science and Technology (South Korea) . [5858-23]

09.40: **Testing the new methods for small-angle rotation measurements,** A. Popiolek-Masajada, J. Masajada, B. Dubik, Wroclaw Univ. of Technology (Poland) . . . . . [5858-24]

Coffee Break . . . . . 10.00 to 10.30

SESSION 6

Room: B13 . . . . . Fri. 10.30 to 11.50

Optical Interferometry II

Chair: **Heidi Ottevaere**, Vrije Univ. Brussel (Belgium)

10.30: **Measurement advances for micro-refractive fabrication *(Invited Paper),*** N. W. Gardner, A. D. Davies, B. C. Bergner, The Univ. of North Carolina at Charlotte (USA) . . . . . [5858-25]

11.00: **Investigation of thermal expansion homogeneity by optical interferometry,** R. Schoedel, Physikalisch-Technische Bundesanstalt (Germany) . . . . . [5858-26]

11.20: **Characterization and engineering of ferroelectric microstructures by interferometric methods *(Invited Paper),*** P. Ferraro, S. Grilli, M. Paturzo, D. Alfieri, P. De Natale, Istituto Nazionale di Ottica Applicata (Italy); M. de Angelis, S. De Nicola, A. Finizio, G. Pierattini, Consiglio Nazionale delle Ricerche (Italy) . . . . . [5858-27]

Closing Remarks

Heidi Ottevaere, Vrije Univ. Brussel (Belgium);

Participants

Names in bold are SPIE Members.

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Technical Abstract Summaries

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Part of Proceedings of SPIE Vol. 5856 Optical Measurement Systems for Industrial Inspection IV

5856-01, Session 1

Modern approaches in phase measuring metrology

J. C. Wyant, The Univ. of Arizona (USA)

No abstract available

5856-02, Session 1

Full-field low-frequency heterodyne interferometry using CMOS and CCD cameras with online phase processing

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Most full-field heterodyne interferometry systems incorporate a complex electro-mechanical scanning device. In this study, however, we present an alternative non-scanning approach based on a low frequency heterodyne interferometer employing standard CCD and CMOS cameras. Two frequency locked acousto-optic modulators were used to obtain two laser beams with an optical frequency difference as low as 3 Hz. The interference of those beams generated a suitably low frequency carrier signal that allowed the use of a 25 frame/second CCD camera. Using a digital CMOS camera and acquiring a limited number of randomly accessible pixels, measurements with mush higher carrier frequencies were also possible.

The phase demodulation algorithms used were based on analytic signal argument and were applied either online, by acquiring short portions of carrier signal, or offline, after the acquisition of a full-history carrier signal. Fast, full-field phase measurement rates of over 10 Hz were achieved with the CMOS camera, this being limited by the frequency of the carrier. The advantages of the heterodyne technique with respect to common phase-stepping methods are the shorter response time and lower sensitivity to sources of uncertainty such as drift, vibrations and random electronic noises. In order to directly compare the heterodyne and phase-stepping techniques experimentally, the same interferometer was used for both methods. The switching between operation modes was achieved by simply altering the electronic driving signals of the acousto-optical devices, where for the phase-stepping mode the frequency difference of the driving signals was set to zero. The phase steps were obtained by a piezo-driven mirror. Comparing the phase difference between two pixels in an image, approximately 0.01 radian of standard deviation was achieved by heterodyne technique, as compared to 0.2 radian by the phase-stepping method.

As an example, the application of the CCD based heterodyne technique to the measurement of the angle made between two faces of a glass plate is described. The interferometer with the CMOS camera was also applied to the measurement of the refractive index variation across a micro-channel where two liquid flows were mixed. Also, the capability for fast, time-resolved full-field optical refractive index measurements was demonstrated. The examples presented show how the high sensitivity of the heterodyne technique allows the study of a number of sources of uncertainty that are not otherwise easily quantifiable using standard full-field methods.

5856-03, Session 1

Fast three-dimensional phase-unwrapping algorithm based on sorting by reliability following a non-continuous path

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In this paper, we propose a novel three-dimensional phase unwrapping algorithm that extends the ihtwo-dimensional phase unwrapping algorithm based on sorting by reliability following a non-continuous pathlo into three dimensions. The proposed algorithm depends on a quality map to unwrap the more reliable voxels first and the less reliable ones last. It follows a non-continuous path to perform the unwrapping process. Computer simulation has demonstrated that the proposed algorithm is more suitable than its two dimensional counterpart when used to unwrap volumetric data.

5856-04, Session 1

Gated heterodyne coherent anti-Stokes Raman scattering for high-contrast vibrational imaging

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Coherent anti-Stokes Raman scattering (CARS) microscopy is a powerful method for chemical imaging which uses molecular vibrations as contrast mechanism. A pump and a Stokes field whose frequency difference is tuned to a Raman band of the molecule under investigation are focused into the sample. As a consequence of the induced third-order nonlinear polarization the blue-shifted anti-Stokes signal is generated. In a conventional CARS microscope one directly detects the anti-Stokes signal while scanning the sample. This allows e.g. in vivo examinations of unstained cells with high spatial resolution or chemical imaging of patterned photoresists on semiconductor surfaces.

One of the main problems associated with CARS microscopy is the contrast reduction due to resonant and nonresonant solvent background signals. Anti-Stokes signals from small scatterers are often buried in these background signals.

We propose a novel detection scheme for CARS named gated heterodyne CARS (GH-CARS) which is capable of completely suppressing background signals. As coherent four-wave mixing process, CARS provides a fixed phase relationship between Stokes, pump and anti-Stokes field. Our technique utilizes this specific property which has been widely disregarded so far for the heterodyne detection of the anti-Stokes signal. From the local oscillator (LO) signal involved one demands phase coherence with regard to the excitation fields. Beside the well-known advantages linked with a heterodyne detection - simple narrow-band filtering and shot-noise-limited detection even in the presence of strong background signals - this work focuses on the possibility to significantly improve the vibrational contrast by means of proper pulse timing.

To demonstrate this novel method, we generated phase-coherent tunable light pulses with three femtosecond noncollinear optical parametric amplifiers (NOPAs) seeded by a common white-light continuum. Appropriately time-delayed probing and heterodyning result in a contrast improvement of more than two orders of magnitude compared to conventional CARS. The scheme exploits the different dephasing times of sample (deuterated benzene) and possible solvent (heavy water).

5856-05, Session 1

Study of polarizing intercorrelative function of coherent images of phase-inhomogeneous layer anisotropy

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In solving diagnostical problems of objects' structure, phase-inhomogeneousness dispersion of which more than unity, such components take part in forming an object field phase, difference of which equals or exceeds pi . In this case field amplitude zeroes are realised in the object field, in which phase and polarization are not determined.

One of the most attractive, from the point of view of physical correction, is the method based on using referent coherent pencil and determination of the degree of the reciprocal correlating between the referent and object fields.

Such results have been obtained:

- probable distributions of visibility of interference pictures within the correlation zones of the object field of statistically phase-inhomogeneous layer have been investigated;

- the influence of referent wave polarizing structure on the interference structural organization of the statistic-laser object field in different diffraction zones has been determined;

- modeling representations on forming random laser field polarizing interference structural organization has been worked out and the polarizing interference system of diagnostics of statistic distribution of the anisotropy parameters of the phase-inhomogeneous layer has been created.

5856-07, Session 2

Reconstruction of in-line hologram using iterative algorithm

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In-line holography is a simple approach for high resolution imaging. It has been extensively investigated due to it can effectively utilize the space-bandwidth of the digital recording instrument, such as CCD or CMOS. However, since the fact that the reference wave and the object wave are overlapped during the hologram was recorded, the reconstructed image is blurred by the ghost image. This shortcoming limits the applications of the in-line holography. Therefore, an effective reconstruction algorithm is important for generalizing the application of the in-line holography. In this presentation, some approaches based on the iterative phase retrieval algorithms are reported for in-line holograms reconstruction. Firstly, the YG algorithm and the GS algorithm are used to reconstruct pure absorption object from their in-line holograms, respectively. The differences between these two algorithms on in-line hologram reconstruction are analyzed.

Then the GS algorithm is extended to reconstruct whole optical field form double or multiple holograms. At last, a new approach for reconstructing object from a hologram series is presented. Experimental results show that all these methods can reconstruct original object well.

5856-08, Session 2

Image focusing properties in reconstructing digital holograms

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In Digital Holography, the amplitude and phase image reconstruction process is performed numerically. In virtue of this fact some image parameters can be controlled and adjusted a posteriori of the digital recording operation. For example in DH it is possible the correction of optical aberrations, control of image size and resolution. One of the most important parameter, especially in microscopy, is the focus to get a sharp reconstructed image in both amplitude and phase. In this paper it will be discussed the focusing image properties in the reconstruction process of digital holograms. Some experimental tests and numerical examples will be shown adopting a digital holography set-up in a microscope configuration. Characterization of different kind of microstructures will be shown and analyzed.

5856-09, Session 2

High-resolution lensless Fourier-transform digital holography

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Nowadays digital holography (DH) is a versatile tool in coherent optical metrology. This powerful method can efficiently substitute classical coherent optical methods in various fields. However, the limited resolution and the nonlinearity of the recording device (CCD camera) restrict the applicability of DH in holographic microscopy.

The aim of this work was to improve the resolution of DH. To achieve this goal we recorded digital holograms of micro lines of width in the micrometer region in a lensless Fourier-transform setup. In such a way spatial frequency of the hologram can be reduced in high numerical aperture geometry. A He-Ne laser was used in the experiments.

Holographic images of the test objects were reconstructed using three methods. The first one is based on fast Fourier-transform algorithm. The second one uses Monte-Carlo method. In the third one the numeric quadrature of the double Fresnel-Kirchhoff integral was implemented. In our paper we present a comparative analysis of the reconstructed holographic images using these methods.

The effects of limited resolution and nonlinearity of the CCD on the reconstructed image were included in the third method by multiplying the integrand of the Fresnel-Kirchhoff integral by the product of two functions, describing of the above characteristic of the CCD.

All the investigated methods were compared to a classical microscopic observation.

This method can serve as a basis for resolution enhancement in DH via de-convolution.

5856-10, Session 2

Determination and applications of contoured windows for ESPI fringe pattern processing

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Speckle fringe patterns of ESPI are full of high-spatial-frequency and high contrast speckle noise which defies normal process methods. Filtering with contoured windows proposed by the authors is proven to be an efficient approach to filter off the speckle noise and reserve the fringe patterns obtained by subtraction of two original speckle patterns. Furthermore, with contoured windows, the contoured correlation fringe pattern (CCFP) method proposed by the authors can derive high-quality fringe patterns of ESPI with speckle-free, smooth, normalized and consistent fringes from two original speckle patterns. CCFP can extract the phase field with a single-step phase-shifting. Determination of contoured windows is a key step in CCFP method. The contoured windows used to be determined by fringe directions only and this process would generate cumulated errors. In this paper, we developed a new technique to determine the contoured windows according to the slope angles of the fringe patterns with the help of the local fringe direction. This new technique can determine contoured windows more precisely and more robustly with no cumulated errors. In addition, we have improved the plate-fit method to get better fringe direction. Some applications of our new contoured windows are also presented in this paper.

5856-76, Session 2

Comparison of B-Spline and Zernike fitting techniques in complex wavefront surfaces

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Zernike polynomial fitting has been the commonplace alternative for assigning a measured wavefront a given shape. However, Zernike polynomials have intrinsic limitations under given conditions, mainly in complex wavefronts with for instance decentered double-peaks or with relevant undulations. The main goal of this paper is analyzing an alternative to Zernike fitting based in B-Spline fitting, comparing the strengths and weaknesses of each representation when applied to wavefront fitting. Simple and complex wavefront cases will be presented and studied, and the quality of their fitted representations using Zernike and B-Spline polynomials will be compared, presenting the main factors relevant in their comparison. Moreover, the case of random white noise added to the estimated data will allow an insight into the expected behavior of both representations when applied to experimental data.

5856-48, Session 3

Recent issues on development of reference materials and standarized tests of optical methods of strain measurement

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The needs of standards in optical methods of strain measurements have been discussed previously and the attention has been switched to the creation of reference materials and standardized tests. Reference materials provide the means of calibrating of measurement system by comparison to the standard that is traceable to international standard. In this way an unbroken chain of comparisons between the measurement system and international standard with defined uncertainties in each comparison is created. A standardized test allows the performance of the measurement system to be assessed against the number of known quantities and such tests should be as challenging as the applications for which the measurement system has been designed. The preliminary design of the reference materials for the optical techniques of strain measurement are presented. Results obtained from the tests of these physical reference materials using digital image correlation, ESPI, grating (moiré) interferometry, photoelasticity, strain gauges, thermoelasticity support the design hypothesis and have aided the refinement of the design. The first set of results produced with the design show the remarkable correlation despite being obtained independently in four different laboratories and countries using six different techniques. Initial design of standard tests has been also created. The concept of virtual standardized test materials has been introduced to allow the performance of algorithms within a measurement to be assessed so that a standard and comprehensive diagnostic and evaluation framework will be available to system designers, manufacturers and end-users.

5856-49, Session 3

Polarization plane rotator used as a phase stepping device in a 2-channel shearing speckle interferometer

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Spatial phase stepping, in contrast to temporal phase stepping, is a preferred method for phase stepping interferometers that are used to measure dynamic events, because in this case phase stepped interferograms are acquired simultaneously instead of sequentially. As an alternative to a one-image approach involving a spatial carrier, polarization phase stepping can be implemented in a multi-channel system. In such systems the reference and object beams have different polarization states. An obvious way to implement polarization phase stepping is to apply a retarding element that effectuates a phase difference between p- and s-polarized light in each optical channel requiring a phase step. It is shown that polarization phase stepping can be implemented too by a polarization plane rotator that establishes a relative phase shift between two counter-rotating circularly polarized beams. The phase step can be made relatively accurate, since it just depends on the accuracy with which the rotator is manufactured, and not on its orientation, as would have been the case for a waveplate. The phase stepping method has been implemented in a one-camera two-channel shearing speckle interferometer, with two optical channels, and a relative phase step of pi/2 between them.

5856-50, Session 3

TV-holographic mapping of airborne sound fields for the design of parametric arrays

K. D. Hinsch, H. Joost, G. Guelker, Carl von Ossietzky Univ. Oldenburg (Germany)

Parametric arrays at ultrasonic frequencies are used in the nonlinear generation of highly directional airborne audio sound. To achieve sound pressure levels as high as possible such arrays are composed of up to several hundred individual piezoelectric PZT-transducer elements of some 10 mm in diameter, each. For optimum performance it is required that these elements radiate in phase. Usually, however, they vary in their resonance frequencies causing corresponding phase shifts at the operating frequency. To control such effects and provide for active adjustments the resulting ultrasonic sound field near the array should be known.

The small variations in the refractive index of the air caused by the pressure fluctuations of a propagating sound wave can be used in the optical monitoring of the sound field. We have modified time-averaged Electronic Speckle Pattern Interferometry (ESPI - also called TV-holography) for this purpose [1]. The speckle pattern from a rigid background wall is viewed through the sound field. After its double pass through this field the object light is phase-modulated at the sound frequency. The changes in the refractive index in air are relatively small - a path of 2 cm in length through a field of sound pressure level 130 dB produces an effect equivalent to an object vibrating at amplitude 3.6 nm. Thus the sensitivity of the method must be enhanced which is done by shifting the operating point of the system to maximum slope by proper reference wave modulation. A 2-Hz frequency difference between sound and modulation frequency produces a beat signal that allows to obtain a set of phase-shifted images required for automatic and unambiguous processing of the data. A measurement thus provides an amplitude and mod2pi-phase map each of the refractive index modulation integrated along the viewing path through the field.

The three-dimensional field is obtained from many such projections through the sound field at different viewing directions. For this purpose the sound source is placed on a precision rotation stage and the measurement is repeated for a sequence of angular orientations. A tomographic back-projection technique [2] especially adapted for an alternating field allows to calculate phase and amplitude distributions for arbitrarily oriented planes in the field. These data are used to tune the output phase from the individual transducers by mechanical vernier adjustment for optimum performance of the complete system.

Results are presented for various sets of combinations of ultrasonic transducer elements.

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5856-51, Session 3

Comparison of shearography and optical fibre Bragg grating strain sensors with resistance foil strain gauge measurements

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Modern manufacturing processes increasingly require the use of advanced techniques for the characterisation of surface strain. This paper addresses the calibration of two such advanced optical techniques: optical fibre Bragg gratings (FBGs) and shearography.

Shearography, also known as speckle shearing interferometry, is a speckle interferometry technique based on the correlation of interferograms, and is capable of providing full-field displacement gradient measurement. The optically rough surface of the object is illuminated by a laser forming a speckle pattern. This speckle pattern is optically mixed in an interferometer to form a speckle interferogram. Speckle interferograms recorded before and after object are correlated, often by subtraction, to yield correlation fringes sensitive to displacement gradient, a parameter closely related to the surface strain. In shearography, full characterisation of the surface strain requires a multi-component measurement, using a minimum of three spatial channels and two shear directions. A coordinate transformation is used to calculate the strain from the measured displacement gradient components.

FBGs are point sensors that are created by introducing a periodic refractive index variation in the core of an optical fibre. UV laser illumination in conjunction with an interferometer, or a phase mask, is used to generate FBG sensors in hydrogen loaded, or photosensitive, optical fibre. The FBG sensors may be affixed to the surface of the object, or alternatively embedded in the material. The FBG sensor selectively reflects a narrow optical wavelength band, centered at the Bragg wavelength, from a broadband source. The Bragg wavelength is sensitive to perturbations in the refractive index or/and period of the FBG. Measurands that interact with the fibre to change the refractive index or/and period, typically temperature and strain, cause a concomitant change in the Bragg wavelength. Measurement of the wavelength shift forms the basis of FBG sensor systems.

In this paper an ABS pipe, loaded by changing the internal pressure between 0 and 83 kPa, was used as the test object. The axial and hoop strains were measured using three techniques: shearography, FBG sensors and resistance foil strain gauges (RFSG). Shearography measurements were performed using a six-channel shearography instrument. In addition to the axial and hoop strains this shearography instrument also measured 4 further surface strain components. FBG sensor measurements were made using six wavelength-division-multiplexed FBGs in a single length of single mode optical fibre, interrogated using a Fabry-Perot based demodulation instrument. Six RFSGs were affixed to the pipe adjacent to the FBG sensors to measure the axial and hoop strains. An analysis of a number of data sets is presented and good agreement was found between the results from the three instruments, and a theoretical prediction of the axial and hoop strains.

5856-52, Session 3

Fast distance sensing by use of the speckle effect

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We propose novel technique for z-distance measurement from an optically rough surface exploiting dynamic speckle pattern. It is well known that when the laser beam is scattered from a moving surface, the speckle patterns becomes dynamic, i.e. it varies in space and in time. In some geometry (particularly, under illumination by a divergent beam), the speckle pattern is moving as whole. In free space the speed of the speckle pattern depends on both the surface speed and the distance from the object surface. The speed of speckle pattern can be measured for example by the spatial filtering method. Thereafter, one can calculate the distance between the object surface and optical system, if the surface speed is known. In our approach we use the fact that the dynamic speckle pattern has near the same behavior even in the case when the object is fixed in the laboratory coordinates but the laser beam scans the surface under study. We use an acousto-optical deflector to perform scanning the surface. The scattered light is than collected into a single photo-diode after being spatially filtered by Ronchi rulings. The electrical signal from the photodiode is modulated at a well-defined temporal frequency. When the distance between the surface and optical system is changed, the modulation frequency changes as well. Therefore, after measuring the modulation frequency we calculate the distance from the surface. Acousto-optical deflector provides surface scanning at very high speed up to 100 m/s resulting in the modulation frequency of about 10 MHz. The response time of all measurement system is about 20 μs, which is limited by the deflection time of our particular acousto-optical deflector with TeO2 crystal. Important parameters of the sensor such as accuracy and range of measurements will be discussed.

5856-53, Session 4

The laser-scanning confocal vibrometer microscope

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Laser-Doppler vibrometry is a widely used technique to measure the instantaneous vibration spectrum of microelectromechanical systems (MEMS). The existing system consists of a scanner unit that is attached on the C-mount of a standard microscope. However, wavefront aberrations of this approach limit the laser-spot diameter to a few micrometers. This lateral resolution is sufficient for most MEMS but current developments on sub-micrometer sized, mechanical structures (nanoelectromechanical systems - NEMS) require lateral resolutions of half a micron or even less. Sub-micrometer lateral resolution for the optical vibration measurement can be achieved when the scanned laser beam of a confocal microscope is the measurement beam of a heterodyne laser-Doppler vibrometer. Such a system is presented in this paper for the first time.

The highest magnification we use currently is a 100x objective lens with a numerical aperture of 0.9. Our measured spot diameter is 730 nm (FWHM diameter is approximately 430 nm), which is 70% above the theoretical limit. But we achieve the theoretical laser-spot size for lower numerical apertures. The resolution of displacement-amplitude measurements is less than 1 pm divided by square root Hz. The signal strength of the interference signal measured with the photodetector in the heterodyne interferometer is a measurand for the light collected by the confocal microscope. This measurand can be used for sectioning imaging.

Therefore, our new system is also an adequate confocal microscope. The sectioning characteristics of the heterodyne interferometer will also be discussed in the paper.

5856-54, Session 4

Accuracy analysis of major signal processing techniques in laser Doppler velocimetry

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Currently, three major techniques are employed for signal processing in Doppler velocimetry:

- Doppler spectral shift measurement,
- correlation measurement and
- zero crossings measurement.

It is shown that spectral measurements do not reveal bias errors and have the random error, which typically does not depend on signal-to-noise ratio in spectral domain with SNR \› 5 in spectral domain.

An analysis of random fluctuations in measured correlation function shows that the variance of its fluctuations takes sharp minimum at correlation function zeros. An experimental study confirms this dependence. Our study shows also that with Doppler frequency shifted from central frequency of electronic processor band there is considerable dependence of position of correlation function zero on signal-to-noise ratio.

The analytical expression for probability density of successional zero crossings as function of SNR and spectral width of Doppler signal is obtained. The position of probability density peak is determined by period of Doppler signal. The experimental study has shown that the expression obtained is in a good agreement with experimental data.

The study of probability density of zero crossings shows that in the region of small signal-to-noise ratios both correlation and spectral measurements exhibit much smaller random errors than zero crossing technique. In the region of higher SNR, however, random relative fluctuations of measured probability density peak position are less than fluctuations of spectral peak position or fluctuations of correlation function zeros.

5856-55, Session 4

Phase shifting aided time average interferometry for vibration investigation: modulation determination error analysis

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By normalizing the time-average interferogram intensity modulation distribution for the vibrating object by the interferogram intensity modulation distribution for the static one the so-called fringe function (i. e., the zero order Bessel function for sinusoidal vibrations) with the vibration amplitude information encoded in its argument can be determined. In the paper the influence of changes of frame average intensities and phase shift errors between the frames on interferogram modulation calculations using the phase shifting method is elaborated and compared with contrast calculations. Identification of main experimental errors using histograms of phase shifts is studied. Experimental results obtained when testing vibrations of silicon micromembranes show good corroboration of numerical findings.

5856-56, Session 4

Development and investigation of high-resolution resonant pressure sensor with optical interrogation

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In this paper we present new family of MOEMS device, which can be used as high resolution optical resonant pressure sensor. The architecture contains a membrane loaded with an optical branch of a Mach Zehnder interferometer (MZI) monolithically integrated on top of Si substrate. The measuring arm of MZI is crossing the MEMS actuator based on a piezoelectric thin film PZT transducer integrated on SOI membrane. The PZT transducer is excited by applying a sinusoidal voltage from a waveform generator. The working principle of MZI read-out is based on the change of effective refractive index of guided waves of MZI, induced by displacements of the deformable structure via the elastooptic effect and waveguide elongation. When the membrane operating at his resonance frequency, the application of a pressure on the membrane produces a significant shift of resonance frequency corresponding to a loaded pressure.

The advanced testing methods for the characterization of dynamic characteristic study of microdevices are necessary. The point-wise measurement system was combined with the multifunctional interferometric platform based on Twyman-Green microinterferometer working in stroboscopic mode.

5856-57, Session 4

Time synchronization of oscillating objects with laser pulse in interferometry

J. Bartold, Warsaw Univ. of Technology (Poland)

Significant progress in MEMS/MOEMS development requires new measurement methods. The strobe interferometry is one of the widely used technique for oscillating object analyses. It is based on object observation during the short laser pulse illumination. In the paper a new method for electronic time synchronization of oscillating objects, laser pulses and camera registration is proposed. The system is developed to measure the silicon micromembrane surface shape. Laser pulse mode properties and camera adaptation to a microinterferometer setup are considered in the paper. A complementary system oriented on the investigation of the relationship between object transient shape changes and oscillation phases was presented. Preliminary results of measurement of silicon membrane shape changes during oscillations were presented.

5856-58, Session 4

Specification of vibrational modes and amplitudes in large-scale structure by time averaging moiré technique

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Specification of vibrational modes and amplitudes of structures are crucial issues in civil and mechanical engineering. Several techniques have been used for this kind of studies, including holographic interferometry, speckle interferometry and moiré technique. But, for large-scale structures modal analysis technique is usually used. In this work we have used time averaging moiré technique to study in plane vibrations of large structures. The study includes specification of vibrating modes and amplitudes of structures. The technique is applied by painting a suitable size linear sinusoidal reflectance pattern on the lateral surface of the structure. As the structure is put into vibration, using a wide-angle high-resolution digital camera, the image of vibrating pattern is recorded in an exposure time much larger than the vibration period. The visibilities of the image along a line parallel to the painted pattern line are derived by processing the reflectance distribution. By dividing the resulted visibilities by the visibility of the image of the static pattern we get the normalized visibility curve. The number of normalized visibilities equal to 1 provides the number of vibrational modes and the magnitudes of the visibility minima or the locations of the zero visibility give the amplitudes of vibration.

5856-77, Poster Session

Novel real-time infrared image processor with ADSP

C. Ge, G. Fan, Institute of Applied Electronics (China)

With ADSP-TS201S, a novel infrared image processor is designed. DSP processors are microprocessors designed to perform digital signal processing-the mathematical manipulation of digitally represented signals. In this paper, the novel Infrared Image Processor (IIP) and the pattern process algorithm run in the processor are designed with DSP chips ADSP-TS201S manufactured by ADI (Analog Device Inc.). There are two signal channels within the IIP. The signals passed through the channels may be same or not. In this case, it is different. There are four pieces of DSPs which utilized parallel procedure and serial procedure. With this design, the sophisticated arithmetic can be operated in the system.The special character of the algorithm is the neural network method.

The purpose of Infrared Image Processor is to construct an infrared image processing system to process the image recorded by infrared CCD with infrared reflective telescope. This system includes Infrared CCD camera (digital video), visible CCD camera, host PC and the Infrared Image Processor with ADSP-TS201S.

5856-78, Poster Session

New approach for simple and rapid shape measurement of objects with surface discontinuities

S. S. Gorthi, K. R. Lolla, Indian Institute of Science (India)

Fringe projection technique for surface profile measurement has been extensively used in industry for fast prototyping, quality control and deformation analysis as it is a non-contact, full field measuring and has high spatial resolution measurement capability. The common procedure involves- projecting a sinusoidal fringe pattern on to the object from an offset angle and recording the image of the pattern which is phase modulated by the topographical variations of the object surface. An automated analysis is then carried out to extract the phase from the deformed fringe pattern mostly using either FFT method or phase stepping method; both of them produce wrapped phase distribution. The

reconstruction of surface profile of objects with inherent surface discontinuities is usually a difficult problem by using standard phase unwrapping techniques. In this paper, a new approach for phase unwrapping is proposed. "Takeda's method" is used to obtain the wrapped phase map. Proposed method of unwrapping makes use of an additional image of the object captured under the illumination of a specifically designed color-coded pattern. The new approach demonstrates, for the first time, a method of producing reliable unwrapping of objects even with surface discontinuities from a single-phase map. It is shown to be significantly faster and reliable than temporal phase unwrapping procedure that uses a complete exponential sequence and compared to it the reduction both in image acquisition and in analysis times by the factor [(log2S +1) / 2] is an important advantage of the present approach (S: Number of fringes in the projected pattern). New procedure suggested and various steps involved in it are illustrated with the help of simulations. Validity of the proposed method is demonstrated from the results obtained by experimenting on an object with step discontinuities.

5856-79, Poster Session

Polarizing-correlative processing of images of statistical objects in the problem of visualization and topology reconstruction of their phase heterogeneity

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The basical idea of such an analysis consists in searching for the interrelation of the Polarizing-Autocorrelative Function (PACF) of a field of the scattered coherent radiation with a surface and inner object's structure. PACF stands for the degree of intercorrelating of object's field polarizing structures; one of them is constant and referent, the other one is filtered by means of the analyser.

Such results have been obtained:

- PACF of the radiation field, scattered by rough surfaces, differs from the extremum of a wide range of analyser's turn angles unsufficiently. Small dispersion of polarization azimuths of correlation zones of a boundary field depends on the high degree of correlation of coherent components.

- Scattering in surface and subsurface layers of phase-inhomogeneous objects forms the considerable dispersion of polarization azimuths. PACF of a boundary field of such objects differs from the extremum essentially.

- The increase of light dispersion multiplicity is manifested in the growth of polarizing discorrelating: PACF of turbid layers. Their values decrease rapidly with the alteration of analyser's turn angle.

The PACF analysis of a boundary field of phase-inhomogeneous layers gave the possibility to work out and approbate the methods of polarizing correlometry of coherent images experimentally:

- The determination of orientation topology of phase heterogeneities of biotissues (skin, muscles) and bioliquids (blood serum, bile).

- The determination of orientation distribution of rough surface elements.

- The determination of birefrigence gradients of statistic layer substance of both organic and inorganic origin.

5856-80, Poster Session

Grid pattern design for fast scene reconstruction by a 3D vision sensor

Q. Guan, S. Chen, Zhejiang Univ. of Technology (China)

This paper presents a method of pattern design for a 3D vision sensor based color-encoded structured light to improve the reconstruction efficiency. Compared with ordinary structured light systems such as spot-light, the system using an LCD projector with line stripes has an advantage that much less images are required for the same number of measured object points in the scene. However, it still needs to take several images (usually 8-12 images) for recovering the 3D scene. As a result, its speed is limited and applications restricted. In general, it can be used to reconstruct stationary objects. For dynamic use, it is not possible to capture more than one image of the same part of an object for perceiving the 3D information of moving or non-rigid objects. In such a case, 3D measurement using a single image is desired.

For this reason, an alterative method is to use a color projector which can be controlled by a computer to generate arbitrary desired color patterns. Different from the case of stripe light vision system where the coordinates on the projector can be determined by analyzing the bit-plane stack obtained from multiple images, the coordinates in the color projection vision system has to be determined in a single image. A problem of the color encoded projection is the unique indexing of the light codes in the image. If all light rays are visible in the image and if each light grid is completely visible then indexing would be trivial. However, in many cases some light grids are invisible or only partially visible due to occlusions and discontinuities of the objects. Therefore it is essential that each light grid be uniquely identified by incorporating the local neighborhoods in the light pattern.

This paper proposes a special method in design of the grid patterns. Once the perspective projection matrices of the camera and the projector relative to a global coordinate frame are computed from the initial calibration, the triangulation for computing the 3D coordinates of object points simply involves calculating linear equations. Experiments are provided to demonstrate the proposed method in practical situations.

5856-81, Poster Session

Focusing action of refractive microloens by rigorous method

J. Liu, Beijing Jiaotong Univ. (China); B. Gu, Chinese Academy of Sciences (China); B. Dong, G. Yang, Institute of Physics (China)

We investigate the focusing action of refractive microlens based on the rigorous electromagnetic theory by boundary element method. We numerically simulate total electric-field patterns, the electric-field intensity distributions on the focal plane, and their diffractive efficiencies at the focal spots for describing the focusing behaviours of these microlenses with continuous and multilevel surface-envelopes. Focusing action of incident beam with a certain angle of inclination is indagated as well. The present numerical and graphical results may provide an useful information for the analysis and the design of refractive elements in micro-optics.

5856-82, Poster Session

Automatic tracing of interference fringes using Fourier filtering, local thresholding and simultaneous horizontal and vertical scans

A. Anand, Institute for Plasma Research (India); V. K. Chhaniwal, M.S. Univ. of Baroda (India)

The interference fringe pattern or the interferogram contains the information about the wave fronts interfering at the detector plane. Therefore an analysis of this interferogram yields the information about the interfering wave fronts. For this analysis identification of all the interference fringes and their extrema are important. There are many methods to analyze an interferogram, like using manual graphical methods, scanning the interferogram with photo detectors to obtain the fringe extrema etc. But these methods are tedious and are erroneous. The use of automatic tracing of these interferograms from their digitized images will be less tedious and yield better information about the wave fronts. There are various methods for automatic tracing of interference fringes. In the simplest method the fringe pattern is thresholded to yield a binary gray level image. Then horizontal or vertical scan lines are used to determine the mid points of each dark and bright fringe. But the method fails when the fringes are nearly parallel to the scan lines. The thresholding of the interferogram as a whole will also introduce some errors. Here a new algorithm is proposed which uses Fourier filtering to remove high frequency noises, local thresholding, and a simultaneous horizontal and vertical scan is proposed. The algorithm selects the type of scan (horizontal, vertical or simultaneous) automatically. The proposed technique is found to yield very good results even for complicated interferograms. Detailed analyses using various interferograms are given.

5856-83, Poster Session

Application of matched digital filters to noisy fringe-patterns from complex wavefronts

J. Caum, J. Arasa, S. Royo, M. Ares, Univ. Politècnica de Catalunya (Spain)

A new technique for processing of noisy fringe patterns with complex fringe shapes is presented . The technique is based in exploiting the capabilities of digital filters, treating the fringe-pattern as a signal to be processed. The main parameters required for designing the filter, and the application of the design methodology to a particular experimental fringe pattern are described in detail. To conclude, the designed filter is applied to experimental noisy fringe-patterns both from complex and simple wavefronts, which are processed without a single change in the parameters of the algorithms. The procedure is completely general, with a very small computational cost, and may be extended to any noisy fringe-pattern to be processed given the fringes are still visible.

5856-84, Poster Session

Focus sensor for an application in a nanopositioning and nanomeasuring machine

R. Mastylo, D. Dontsov, E. Manske, G. Jäger, Technische Univ. Ilmenau (Germany)

A focus sensor on the basis of a hologram laser unit was developed and successfully tested in a nanopositioning- and nanomeasuring machine as null indicator. The high resolution of the focus sensor is determined by

high precision optical adjustment and special solutions in the electronic parts. So irregularities of the sensor function caused by back reflected light inside of the assembly could be completely eliminated by means of the special high frequency modulation and laser power stabilisation. Common mode noise reduction provides the high SNR ratio of the output signals.The measurements are made in dynamical principle by permanent difference formation between the output signal of the focus sensor and the length value of the z-interferometer of the nanopositioning and nanomeasuring machine. The measuring results and possibilities are represented.

5856-85, Poster Session

Application of super image methods in digital holography

J. Kornis, B. Gombkötö, Budapest Univ. of Technology and Economics (Hungary)

Digital holography is a powerful new tool in the coherent optical metrology. In this method the holographic pattern generated by the reference and object beams is recorded by a high resolution CCD camera. Because the resolution of the electronic devices are still lower than holographic emulsions, a special optical arrangement is used to record digital holograms. The reconstruction of the electronically recorded holograms can be done in the computer based on the fast Fourier transformation (digital reconstruction). Using a special optical device the spatial light modulator (SLM) the reconstruction of the scattered light from the object is possible too (analog reconstruction).

As in the classical holography, a major issue in digital holography is the enhancement of the resolution of the digital holograms. It means not only the enhancement of the image quality, but the extension of the upper measuring range too. One natural way can be the application of higher resolution recording devices. Unfortunately the price of a doubled resolution camera is approximately fourfold.

In the presentation a different way of the resolution enhancement is shown.

The resolution enhancement (building the super image) is based on the building of well sampled so called super images from a set of under sampled but dithered input images. Such methods are originated from the drizzle method, and from the Fourier spectrum combination method.

Using these methods not only the resolution of the digital hologram can be increased, but the object distance also can be dramatically shortened.

5856-86, Poster Session

Phase evaluation using interference of polychromatic light and colorimetric analysis

P. Novák, J. Novák, A. Mik‰, Czech Technical Univ. in Prague (Czech Republic)

Measurements of very small phase changes in optics are usually performed by interferometric methods on the basis of evaluation of interference patterns that corresponds to a specific phase change of the investigated wave field. Our work presents a simple method for evaluation of small phase variations that uses the interference of polychromatic light. The phase change has effect on the colour of the interference pattern, and every colour of the interference pattern can be assigned to a specific phase change that can be evaluated using colorimetric methods. The proposed method offers accurate results and it is suitable for practical utilization in optical industry.

5856-87, Poster Session

Wavelet transform analysis of truncated fringe patterns in 3D surface profilometry

S. S. Gorthi, K. R. Lolla, Indian Institute of Science (India)

The automatic measurement of an object shape is very important in industrial quality control, machine vision and solid modeling applications. Among a wide verity of existing 3-D object profilometry methods Fourier transform profilometry (FTP) is the most popular one. Even though FTP has grown into a mature technique, because of the use of Fourier transform it inherently suffers from the leakage effects in most of the practical situations. An important restriction on the applicability of FTP is that: the image of the recorded pattern should be periodic; if not energy leakage will occur. This introduces errors in the estimated phase distribution of the deformed fringe pattern and so in the reconstruction of the surface profile. Very recently, use of Wavelet transform analysis in phase recovery from projected fringe pattern for 3-D shape measurement was introduced and its advantage over FTP with respect to the applicable limit (maximum measurable slope of object surface) was demonstrated. In this paper, Wavelet transform profilometry (WTP) is investigated. The present communication specifically outlines and evaluates the errors that creep in to the reconstructed profiles when fringe images do not satisfy periodicity. Three specific cases that give raise to non-periodicity of fringe image are simulated and leakage effects caused by each one of them are analyzed with continuous complex Morlet wavelet transform. Same images are analyzed with FFT method to make a comparison of the reconstructed profiles with both methods. Simulation results revealed a significant advantage of WTP, that the distortions that arise due to leakage are confined to the locations of discontinuity and do not spread out over the entire projection as in the case of FTP.

5856-88, Poster Session

Evaluation of spectral modulated interferograms by the extended Kalman filtering method

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Spectral modulated interferograms are formed in white-light spectral-domain interferometer combined with a subsequent spectrometer [1] to obtain a channelled spectrum, which characterizes dispersion of optical samples and allows evaluating distances and displacements. Recently, we have demonstrated application of the phase locked loop (PLL) method to evaluate phases into spectral modulated interferograms [2]. The PLL method has been realized in iterative mode which provides the unwrapped phase recovery. The disadvantage of the PLL method consists in the need of preliminary accurate normalizing of spectral fringes and iterative operation mode, when fringe frequency mean value is unknown a priori.

In the paper, we suggest to apply for processing spectral fringes the extended Kalman filtering method that was recently described in detail [3]. The method provides dynamic evaluation in parallel fringe background, envelope and unwrapped phase within singe fringe sample series. Due to adaptive properties of the method, it is possible to evaluate fringes with initially varied parameters in comparably wide range. The accuracy of the extended Kalman filtering method has been investigated via the comparison of the unwrapped spectral fringe phase obtained by processing the recorded spectral interferograms with the phase resulting from knowledge of both dispersion in the interferometer and the OPD between interferometer beams. Experimental results obtained when processing recorded spectral interferograms are presented.

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5856-89, Poster Session

A compact frequency-stabilized Nd:YVO4/KTP/I2 laser at 532 nm for laser interferometry and wavelength standards

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A compact, solid-state, diode-pumped laser at 532 nm stabilized in frequency on one of the electronic transitions R(56) 32-0 of the absorbing molecule 127I2 has been developed and investigated. The active medium, Nd:YVO4 pumped by the laser diode at 808 nm generates radiation at 1064 nm. A KTP crystal is used for intracavity frequency doubling. Third-harmonics techniques are used for frequency stabilization with an external iodine cell, which is 10 cm in length. The dimensions of the laser head, which includes the iodine spectroscopy layout, are 80 mm Å~116 mm Å~ 130 mm, with a mass of about 1.5 kg. The electronics unit for the power supply, five temperature control systems of the laser elements and of the iodine cell finger, and that of servo electronics for frequency stabilization are uniform in size (213 mm Å~120 mm Å~ 280 mm) and fit into a standard 19" rack. The mass of both electronics units is about 5.2 kg. The frequency stability in terms of Allan variances is 2Å~10-12, 1Å~10-13 and 3.1Å~10-14 at the time intervals of 0.1 s, 10 s and 100 s, respectively. The laser output power at 532 nm is greater than 4 mW.

Such lasers will find wide applications in laser displacement interferometry, in laser interferometers of absolute gravimeters and in laser spectroscopy. These lasers can be also used as portable secondary wavelength (frequency) standards at 532 nm.

5856-90, Poster Session

An objective measure of the quality of honed surfaces (stand-by oral presentation)

F. Puente Leon, Technische Univ. München (Germany)

The quality of the honing texture on cylinder bores of combustion engines plays an essential role with respect to oil consumption, noxious emissions, and running performance. For many years, surface finish has been analyzed based on first-order statistics by using the roughness average parameter Ra as a primary means. Nowadays, the lateral geometry is also being taken into account to enable an assessment of torn and folded metal, burnishing, pull outs, and hone crosshatch. For this purpose, commonly fax film replicas are generated and then analyzed visually by experts.

This contribution presents an algorithm to extract a new measure of the quality of honed surfaces from 2D intensity or topography data, allowing thus an objective assessment of their texture. The method is based on an adaptive separation of the surface data into two complementary components—the groove texture and the background data. Following, from these separation results, a scalar feature is computed that describes the texture quality compactly and reliably. Based on a series of fax film replicas of real honing textures showing different degrees of quality, the principle of the algorithm is illustrated. Moreover, the usefulness of the proposed approach is demonstrated by comparing classification results based on the new measure with ratings of experts. In all cases, a correct class assignment could be achieved.

5856-93, Poster Session

Wavefront reconstruction with the adaptive Shack-Hartmann sensor (stand-by oral presentation)

L. Seifert, H. J. Tiziani, W. Osten, Univ. Stuttgart (Germany)

The adaptive Shack-Hartmann sensor (ASHS) is a variation of the conventional Shack Hartman sensor which uses an dynamic Liquid Crystal Display (LCD) in replacement of the static diffractive or refractive microlens array. The LCD is used to display an array of Fresnel microlenses. The microlenses can be adapted to the wavefront to enhance measurement accuracy and dynamic.

Because of the relatively large pixelsize of the LCD the diameter of the microlenses is larger than in a conventional sensor. The number of microlenses is limited by the resolution of the LCD and is smaller than in a conventional sensor. These characteristics require considerations when restoring the wavefront phase from the measured values. High precicision wavefront reconstruction is done with matrix inversion algorithms. We present two methods suitable for the ASHS: The classic Zernike approach and a novel BSpline algorithm. We will compare these two methods on the basis of fit accuracy, reconstruction time, and the effect of noise and missing data points.

5856-94, Poster Session

A new approach for measurement of wire diameter by optical diffraction (stand-by oral presentation)

Y. C. Diwan, K. R. Lolla, Indian Institute of Science (India)

Non-contact measurement of wire diameters from 5 to 100 microns is a challenging problem in industry and research environments where optical diffraction is invariably used. Traditionally, an interference fringe pattern is generated from diffraction of a collimated laser beam by the wire. A CCD camera collects the pattern and diameter is estimated from separation between successive minima. Diffraction pattern images introduce uncertainty in locating minima due to noise originating from imaging system and blurring by lens. Therefore, measurements are not to the satisfaction. There are continuous efforts to improve accuracy by refining models used for fitting the diffraction data and by developing noise robust minima search algorithms. This communication presents a new approach for diffraction pattern analysis based on noise robust, sub-pixel phase-correlation technique. Phase-correlation is a well-known technique based on Fourier shift theorem for estimating translation of a moving object from a pair of its images. Diffraction pattern of a wire comprises of equal order fringes lying on either side of central maximum and featured by identical distribution of intensity with mirror symmetry. The proposed approach treats the diffraction pattern as a collection of replicas in the form of equal order fringes which when cropped as separate images can be visualized as time-lagged frames of a moving object. For the first time, this treatment has enabled application of phase-correlation for diffraction data analysis. Using this treatment, separation between identical order fringes is found out from which wire diameter is estimated. Robustness of the approach to noise is enhanced by singular value decomposition and Gaussian filtering schemes. Experimental results have demonstrated measurement accuracy better than 0.1 & 0.7 micron for slit width and steel wire diameter respectively lying in the range of 250 to 450 microns.

5856-95, Poster Session

Easy calibration of a structured light vision system based on neural networks

S. Y. Chen, B. Xia, Zhejiang Univ. of Technology (China)

The structured light vision system consists of a CCD camera and a digital projector, which is proved able to provide a means of accurate 3D reconstruction of a scene. For such a system, the inputs are 2D-projections of 3D world objective things and the task of machine vision is to reconstruct the objective world according to the two-dimensional projection pictures. In this course, it is unavoidable to determine the relative position, the direction and internal and external parameters of the camera and the projector or their combined projection matrices. Traditional calibration that relates the 3D world coordinates of a point on the two images is difficult for implementation and the measurement accuracy is dependent on the approximation of camera model. However, the projection model for both the camera and projector is very complicated because of distorted and nonlinear factors in it. It is unlikely to accurately model a camera with only a few parameters even considering some lens distortions.

In order to simplify the system calibration and 3D reconstruction, this work presents a new calibration method that based on neural network is brought forward according to the characteristics of neural network and vision measurement. The relation between spatial points and image points is established by training the network without the parameters of the camera and the projector, such as focus, distortions besides the geometry of the system. The training set for the neural network consists of a variety of lighting patterns and their projected images and the corresponding 3D world coordinates. Such a calibration method has two distinct advantages. It possesses the complicated nonlinear relation between two-dimensional information and three-dimensional information with the neural network, which can include various kinds of distortion and other nonlinear factors during the imaging period. The inherent parallel running ability of the network will make the measuring speed of the network very fast.

Both simulations and real data are used to demonstrate and evaluate the procedure. From the result of training we can find out that through the neural network, it may avoid non-linear operation and obtaining the three-dimensional coordinates directly. The reconstruction error is up to 0. 1mm, whilst the error by traditional calibration method is about 1mm. So the method on the basis of improved neural network can carry on the three-dimensional vision calibration very well, the precision is higher than the linear method and can meet the requirement of common industrial applications.

5856-96, Poster Session

Effectible factors in optics profile testing

H. Ren, X. Jiang, Z. Huang, H. Xu, W. Zhong, L. Liu, Laser Fusion Research Ctr./CAEP (China)

As a key specification of the beam quality control, the profile of the optics requires hi-precise testing, which is indispensable during the R&D of high power laser drivers. Currently, the commercial interferometers provided by such companies as Veeco , Zygo and 4D in US and Fuji in Japanese are widely used in profile testing of optics. However, during our practice, a fairly good accordance can not be found after a series of the profile tests of the optics. Generally, there're certain fluctuations or even remarkable difference among the testing results occurring in the testing results compared with the design specifications. In order to improve the existing poor accordance of the testing results of profile specifications of the optics, and in accordance with our repeated experiments, the Main factors that affect the profile testing are presented respectively, as well as their corresponding impacts upon the profile based on the clarified evaluation parameters and unified testing principles, which are of significant reference value to standardize the testing method of optics profile and to strictly control the optics quality.

5856-97, Poster Session

A compact shearing interferometer for testing optical systems

J. Novák, P. Novák, A. Mik‰, Czech Technical Univ. in Prague (Czech Republic)

An experimental technique for testing the image quality of microscope objective lenses and other optical systems is described. Our work deals with a theoretical analysis of properties of a small and compact shearing interferometer, which was designed, manufactured and tested on several microscope objectives. The designed shearing interferometer can be used for testing the quality of optical systems, e.g. microscope objective lenses and camera lenses. The proposed shearing interferometer enables to determine the residual wave aberration of the tested optical system (e.g. microscope objective lens). The device is characterized by very small dimensions, which provide its easy portability. The described compact

shearing interferometer is practically insensitive to vibrations and the mechanical design is also very simple. The proposed evaluation method offers very accurate results and it is suitable for practical utilization in optical industry. The interferometer is suitable for testing laboratories and service engineers in the field of optical microscopy. The same interferometer can also be used not only for wave aberration measurement, but also for measurement of the modulation transfer function (MTF) of tested optical systems.

5856-98, Poster Session

500-mm-aperture wavelength-tuning phase-shifting interferometer

L. Chai, Q. Xu, Fine Optical Engineering Research Ctr. (China); Y. Yu, Shanghai Univ. (China); Y. Deng, Fine Optical Engineering Research Ctr. (China)

A 500-mm-aperture wavelength-tuning phase-shifting interferometer has been developed in FOERC applied to the measurement of large optics. Also it can switches to a smaller 130-mm-aperture. This paper describes the optical and mechanical design as well as calibration technique of system and 13-frame phase-shifting algorithm design.

Optical design applies Fizeau-style and the light source is a tunable diode. To improve the expandable ability of the system, a reflective mirror is used to switch between large and small aperture and consistency of optical axis is ensured through mechanical design. Equipped with our precise optical polishing technique, high precise TF and RF are obtained.

In our study, an analog voltage input is applied to the Frequency Modulation port of laser controller converted by a Digital/Analog converter. By sub-division the voltage, we realized wavelength resolution about 10-6 nm which is enough to satisfy the need of optical testing. Two simple and effective methods are adopted to correct relationship between cavity length and applied PZT voltage and phase step . One is the geometry way and the other is to use statistical method by repetitive measurement many times.

A 13-frame phase-shifting algorithm is designed using Hanning window, where phase step is π/2.

A Zygo 4 inch standard flat which nominal PV errorλ/20 is used to evaluate the accuracy and repeatability of our wavelength-tuning phase-shifting system . 1σrepeatability error of PV and RMS is about 0.003λ and 0.0008λ respectively .

5856-100, Poster Session

Possible application of hyperchromatic optical systems for metrology of surfaces

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The problems of topography of surfaces are very important in various parts of science and engineering. Several approaches exist for measurement of surface figure and roughness. Measurement methods can be divided into two distinct categories, contact and non-contact techniques. Our work describes a relatively simple method for topography measurements that uses special optical systems (hyperchromats) with a linear dependence of longitudinal chromatic aberration on the wavelength of light. The aim of this work is to show a possible application of hyperchromatic optical systems for topography of surfaces. The work describes a basic analysis of parameters of hyperchromats, i.e. optical systems with large longitudinal chromatic aberration that is in our case linearly dependent on the wavelength of light. On the basis of the performed analysis, it can be designed such optical system (optical sensor) that permits to perform measurements of topography of surfaces, i.e. determine a figure or roughness of surfaces. The sensor uses polychromatic light and relatively simple experimental arrangement. The proposed measurement technique seems to be quite simple and cost effective with respect to other measurement methods.

5856-101, Poster Session

On-line measurements with optical scanners: metrological aspects

V. Duma, Univ. of Arad (Romania)

The paper presents the results of an on-going research regarding the optical scanners with rotating, plane or polygonal mirror, used in the on-line, dimensional industrial measurements. Altough this particular area of applications is considered, the results that have been obtained are also valid for others, different kinds of applications of the laser scanners. The parameters of the two devices considered are deduced, in a comparative look, in a rigouros mathematical approach, different from the one in the state-of-the-art. The sources of errors in the scanning process are analysed, and from this, several new solutions for the reducing or for the compensation of the errors are obtained. The main problem presented is the non-linearity of the functioning characteristic and the possibilities of linearizing it - both for the plane and for the rotating mirror device. From the discussion, a designing calculus of the polygonal scanners results, on different cases, with regard to the requiered value of the duty-cycle. The study is completed, for each scanner, with an experimental part, that verifies the theoretical results.

5856-104, Poster Session

Improving 3D surface feature extraction and measurement on metallic surfaces

R. Kokku, GE Global Research (India); G. W. Brooksby, GE Global research (USA)

3D surface measurement of machine parts is challenging with the increasing demands for micron level accuracy and speed of measurement. Optical Metrology based techniques using stereovision faces unique challenges in feature extraction due to the complex surface of the machine parts & varying surfaces. Structured laser light is often used to uniquely define and extract the features of the surface. When the laser light interacts with the metallic surfaces, due to various surface phenomenon of light like scattering, multiple reflections; projected laser light diffuses or reflects inducing new features on surface (Double Bounce effect]. These newly generated features misguide the surface reconstruction. Sub-pixel feature extraction is also effected by the speckle noise, biasing due to sampling, shape etc. Methods based on edge detection, LoG, Hessian, Canny are used to extract features for 3D reconstruction. But the accuracy of this techniques relay on the intensity of the captured features. But with the varying shape the intensity of the laser light projected may scatter the light away from camera, providing small signature.

In this paper, we propose new method for accurate feature extraction and surface reconstruction. Proposed approach based on skeletonization & template guidance suppress the scattered light while detecting the features from multiple images. Tangent technique improves the sub-pixel feature accuracy from the noise, biasing errors. Algorithm is tested on metallic surfaces with varying twisting angles and bends. Results proved efficient reconstruction of surface in the scattered regions and reduction of sub-pixel error in localization by ~30% (variation ‹±5 mils).

5856-107, Poster Session

Zeeman laser for straightness measurements

J. Rzepka, G. Budzyn, Politechnika Wroclawska (Poland) and Lasertex Co. Ltd. (Poland); W. Fraczek, M. Bielenin, Lasertex Co. Ltd. (Poland)

In the paper we are presenting the prototype of straightness measuring devices using the frequency stabilized zeeman He-Ne laser. The He-Ne laser line is split by zeeman effect into two circularly polarized laser beams. The frequency of the radiations differ of 1,2 MHz. The surface stabilized ferroelectric liquid crystal cell is used to stabilize the laser frequency. As the result of the laser frequency stabilization the power of both radiation is equal. The circular polarizations of two laser beams are converted to two linear polarizations perpendicular each other. The two laser beams pass close to the measured axis. Along the axis the analyzing probe is moved. The analyzing probe change the ratio of the power of the horizontal to the vertical polarization. This ratio is analyzed by the receiver composed from the ferroelectric liquid crystal switcher, the polarizer and the detector. The straightness of 2 m long optical bench was measured with this techniques. The resolution was 0,1 μm and the accuracy 7 μm. The accuracy of presented technique is not so good as in the methods using laser interferometer but is comparable with methods using PSD, quadrant detectors or CCD in the same time offering bigger resolution.

5856-108, Poster Session

How to avoid object caused illumination effects in 3D fringe projection

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3D measurement of the shape of rough structures can be realised with the structured light illumination techniques. Some problems can arise while measuring complex object geometries with this technique. Complex objects are characterized, f. e., by deep holes, walls, concave and convex corner like shaped surface structures. When illuminating the object one part of the object can “illuminated” an other one, yielding to spurious fringe patterns locally. Due to these spurious fringe patterns the phase values are strongly distorted increasing strongly the measurement noise locally.

Here we propose methods how to detect and to avoid these spurious fringe patterns. The idea is to use the overestimated information which is in the graycode and the sinusoidal intensity distribution. On the basis of this an operator is defined which result in a mask operation and a phase value correction locally.

With the new method we can reduce the noise amplitude. Hence, the complete surface of objects can now be measured with higher accuracy. As

the most important consequence of our new method, the access of measurements to edges and other structures of objects has considerably improved, and more details can be obtained. In the paper the detection and reduction of the illumination effect using this operator will be demonstrated while measuring different object geometries.

5856-109, Poster Session

Object surface topography by means of a speckle correlation

P. ·míd, P. Horváth, P. Wagnerova, M. Hrabovsk˘, Palack˘ Univ. (Czech Republic)

In this paper we present an optical method based on speckle pattern correlation for measurement of the topography of a surface of an object under investigation. When this object is illuminated with coherent laser beam the arising speckle pattern bears information about the height profile of the object. The resolution of this method is influenced by geometrical parameters of optical measurement set-up. The designed experimental set-up for the measurement of the slope of the object with rough surface is described. Achieved results are presented in comparison with theoretic values.

5856-110, Poster Session

Focal spot measurement in ultra-intense ultra-shot pulse laser facility

L. Liu, P. H. Sheng, K. Zhou, Laser Fusion Research Ctr./CAEP (China)

Abstract：Over the past ten years, there have been rapid developments in generating high peak power, ultra-short pulse Ti:sapphire laser by incorporating the technique of chirped pulse amplification (CPA), and a number of large facilities have been built. Such laser sources are making intensities approaching ~1021W/cm2 available for the study of strong-field physics applications. As laser intensities play the dominating role in strong-field physics, high-power laser systems with short pulse durations and small focal spots have continuously been pursued.

In 2003, scientists at JEARI reported that 0.85-PW, 33-fs laser pulse from a Ti:sapphire laser system has been generated. The spatial quality of the amplified laser pulses was 1.2 and 3.2 times diffraction limited in the horizontal and vertical plane, respectively. With an f/1 parabolic mirror, they expected the laser pulses can be realize a focused intensity of 3.8´1021 W/cm2, and with deformable mirror devices, that would push the diffraction-limited focal spot into a higher focused intensity (\>1022 W/cm2).

We have successfully built a 286-TW Ti:sapphire laser system referred to as SILEX-I(Super Intense Laser for Experiments on the Extremes). With a Shack-Hartmann sensor measurements before the final compressor, we obtain the beam with a wavefront distortion of 0.63mm PV and 0.09mm RMS. The focal spot with an f/1.7 OAP is smaller than diffraction limited, to our knowledge, this is the best far field obtained for high-power ultra-short pulse laser systems with no deformable mirror wavefront correction. The peak focused intensity of ~1021W /cm2 were calculated.

5856-111, Poster Session

Coherent introscopy of phase-inhomogeneous surface and layers

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The paper deals with the investigation of the possibilities of diagnostics of optical-geometrical parameters of statistic objects microstructure.

It has been demonstrated that:

1. The complex of object field correlation zones of light-scattering surfaces and layers, together with the amplitude-phase one, possesses the polarization type-and-form structural organization and their probability density can be determined by the totality of interaction mechanisms of probing radiation according to the object's surface and inner components.

2. Dielectrical rough surfaces form the totality of correlation zones of a boundary field with random values of polarization azimuths. Their probability density in a single dispersion approximation is interconnected with the function of angle-inclination distribution of surface quasi-elements. The diagnostically important interrelation based on research of local polarimetry high-precise systems has been obtained. It gives the possibility to measure a surface relief with the accuracy 1'-5'. The same results have been obtained for the other (metal, semiconductor) types of optically rough surfaces.

3. The subsurface optically inhomogeneous (cracked) layer of polished transparent objects is manifested for the totality of statistically distributed azimuths and polarization ellipticities of object field correlation zones. Under condition of a single dispersion random values of azimuth and polarization ellipticity within the correlation zone are connected with the spatial-angular orientation of the highest speed axis and the value of birefrigence volume of the inner component of the transparent layer. It allows to work out a diagnostics system of their optical heterogeneousness.

4. The object field of volume-scattering layers is characterized by the wide change interval of the speckle azimuths and polarization ellipticities. With the increasing of optical thickness the polarizing structure of multi-scattered coherent radiation approximates to the distribution of the equiprobable types and forms of 100% polarizing local elements.

5856-113, Poster Session

Phase correlation method for subpixel in-plane vibration measurements of MEMS by stroboscopic microscopy

B. Serio, J. J. Hunsinger, D. Teyssieux, B. Cretin, Lab. de Physique et Métrologie des Oscillateurs (France)

Accurate estimation of displacement between successive images is a significant topic in the measurement of in-plane vibrations of microscopic objects such as micro-actuators.

Actual subpixel motion estimation algorithms require the interpolation of interpixel values which undesirably increases the overall complexity and data flow and deteriorates estimation accuracy.

Methods that do not use interpolation for achieving subpixel accuracy are scarcer in the literature.

One approach for subpixel movement estimation without interpolation is based on phase correlation algorithm.

This algorithm estimates the relative shift between two image blocks by means of a normalized cross-correlation function computed in the 2-D spatial Fourier domain.

Indeed, the method is based on the Fourier shift theorem.

The cross power spectrum of two images, containing subpixel shifts, is a polyphase decomposition of a Dirac delta function.

By estimating the sum of polyphase components one can then determine subpixel shifts along each axis.

Phase correlation is the state of the art for interpolation-free subpixel shift measurement between two frames, but this method is strictly limited to subpixel shifts.

So, we have implemented this method using a standard optical microscope in order to observe subpixel translations with high spatial resolution measurements (down to 1 nm in the best cases).

In this paper, we propose an application of this method to characterize the vibration mode shapes of a small silicon beam used in near-field acoustic microscopy.

Harmonic movements of a few tens of nanometers are measured and presented.

5856-114, Poster Session

Experintal studies of mechanical joints by automated grating (moire) interferometry (stand-by oral presentation)

G. Dymny, Warsaw Univ. of Technology (Poland); D. Boronski, Univ. of Technology and Agriculture (Poland); M. Kujawinska, L. Salbut, Warsaw Univ. of Technology (Poland)

Current design, analysis and control engineering applications require effective experimental methodologies and tools for determination of displacement and strain fields as well as material characterization. One of the most important problem in engineering objects is proper design and quality of joints between elements in the form of welds, glued and riveted joints and many others specificly the fatigue and fracture mechanics problems in joints are difficult to analyze numerically, therefore they need experimental support. In the paper we present the results of static, dynamic and fatigue experimens performed by grating (moiré) interferometry systems. These full-field optical extensometers provide information about in-plane displacement field (u,v) and strain fields (εx, εy, γxy) in the region of joint subjected to various modes of loads. It is shown that proper design of full-field extensometer (insensitivity to vibration, good quality of interferogram, automatic analysis of long series of interferograms) allows to use directly at conventional loading machine in workshop environment and for long term fatigue tests.

In the paper we present results of studies of:

- conventional laser welds (static, fatigue tests),

- friction stir weld (static tests),

- riveted joint (static, fatigue tests).

The local experimental maps of displacements and strain are compared with FEM predictions and disscused. The methodology of determination of local material constants in mother material, heat effected zone and joint itself (inc. Poisson ratio, Young's modulus) is given. The future trends in hybrid experimental-numerical analysis of joints in conventional and novel material are discussed.

5856-117, Poster Session

Close infrared thermography using an intensified CCD camera: application in nondestructive high resolution evaluation of electrothermally actuated MEMS

B. Serio, J. J. Hunsinger, Lab. de Physique et Métrologie des Oscillateurs (France); F. Conseil, P. Derderian, MBDA France (France)

This communication proposes the description of an optical method for thermal characterization of MEMS devices.

The method is based on the use of an intensified CCD camera to record the thermal radiation emitted by the studied device in the spectral domain from 600 nm to about 850 nm.

The camera consists of an intensifier associated to a CCD sensor. The intensification allows for very low signal levels to be amplified and detected.

We used a standard optical microscope to image the device with sub-micron resolution.

Since, in close infrared, at very small scale and low temperature, typically 250°C for thermal MEMS (Micro-Electro-Mechanical Systems), the thermal radiation is very weak, we used image integration in order to increase the signal to noise ratio.

Knowing the imaged materials emissivity, the temperature is given by using Planck's law.

In order to evaluate the system performances we have made micro-thermographies of a micro-relay thermal actuator.

This device is an "U-shape" Al/SiO2 bimorph cantilever micro-relay with a gold-to-gold electrical contact, designed for secured harsh environment applications.

The initial beam curvature resulting from residual stresses ensures a large gap between the contacts of the micro-relay.

The current flow through the metallic layer heats the bimorph by Joule effect, and the differential expansion provides the vertical displacement for contact.

The experimental results are confronted to FEM and analytical simulations. A good agreement was obtained between experimental results and simulations.

5856-118, Poster Session

Measurement of beating effects in narrowband multimode Lamb wave displacement fields in aluminum plates by pulsed TV Holography

J. L. Fernandez, C. Trillo, A. F. Doval, D. Cernadas, C. Lopez, B. V. Dorrio, M. Miranda, F. Rodriguez, Univ. de Vigo (Spain)

Narrowband ultrasonic surface acoustic waves are of the greatest current interest for the nondestructive testing of thin-walled members and shell structures like plates, pipes, bridge girders, cans and many others.

The measurement and characterization of ultrasonic displacement fields of Lamb waves by pulsed TV holography (TVH) is presented. Narrowband ultrasound is generated in a few millimeters thick aluminum plate by the prismatic coupling block method using a tone-burst excitation signal in the range of 1 MHz. At this frequency, the plate supports only a few Lamb wave modes, mainly the Ao and So ones. The simultaneous presence of these modes produces a beating clearly detectable as a spatial amplitude modulation.

Our self-developed TVH system performs the optical phase evaluation by the Spatial Fourier Transform Method and renders the instantaneous out-of-plane mechanical displacement field along the whole inspected area. From this field, the wavenumber of each Lamb mode can be obtained and, by combining them with the value of the ultrasound frequency and with the Rayleigh-Lamb theoretical frequency spectrum, information about the elastic constants of the specimen material is obtained.

5856-123, Poster Session

3D optical measuring technologies and systems for industrial inspection

Y. V. Chugui, Technological Design Institute of Scientific Instrument Engineering (Russia)

The results of the R & D activity of TDI SIE SB RAS in the field of 3D optical measuring technologies and systems for noncontact optical dimensional inspection applied to atomic and railway industry safety problems are presented. This activity includes investigations of diffraction phenomena on some 3D objects, using the original constructive calculation method [1].

Increasing of articles quality and their miniaturization takes R & D dimensional inspection noncontact meters of new generation with very high resolution (from 0.01mm to 0.1mm), high speed of response (more than 103 meas./s), as well as wide range of measurements (from tens of mm to tens of millimeters). The most promising is the using the Fresnel diffraction images of inspected objects for measuring purposes. We have studied the influence of the illumination beam nonuniformity on the measurement accuracy. The achieved experimental error under the measurements of objects in the range of 0.5-18 mm was about 0.5-2 mkm.

The inspection method for extended holes (up to 1 m) with small diameter (less than 10 mm) using diffractive optical elements with ring response is considered. The proposed method allows to measure the holes diameters, axis straightness deviation and deviations of hole surface shape. Experimental error doesn't exceed 5 mkm.

Ensuring the safety of nuclear reactors and running trains as well as their high exploitation reliability requires a 100 % noncontact precise inspection of geometrical parameters of their components. To solve this problem we have developed shadow, structured multipoint illumination, low coherency methods and produced the technical vision measuring systems LMM, CONTROL, RADAR, and technologies for noncontact 3D dimensional inspection of grid spacers and fuel elements for the nuclear reactor VVER-1000 and VVER-440, as well as automatic laser diagnostic system COMPLEX for noncontact inspection of geometric parameters of running freight car wheel pairs.

The performances of these systems and the results of industrial testing are presented and discussed. The created devices are in pilot operation at Atomic and Railway Companies.

5856-124, Poster Session

Filter radiometer based realization of photometric scale traceable to cryogenic radiometer at UME

M. Durak, F. Samadov, TUBITAK National Metrology Institute (Turkey)

This work presents the progress made in primary level photometric measurements at the National Metrology Institute of Turkey (UME). A Cryogenic Radiometer (Oxford Instruments Radiox) was employed in the optics laboratory as an absolute primary standard. Temperature-controlled filter radiometer constructed from three-element silicon trap detector, band-pass filters and precision aperture. Filter radiometers were calibrated using the cryogenic radiometer at discrete laser wavelengths of vertically polarized tuneable Ar+, fixed He-Ne and Nd: YAG (with second harmonic) laser sources. Luminous intensity unit of candela was realized with an expanded uncertainty of 2.88x10-3 and photometric scale was re-established depending on this detector-based realization. Candela realization was performed on optical bench using traditional Osram Wi41/G type incandescent light source and an absolute filter radiometer.

Other derived units of photometry that are luminous flux, illuminance, color temperature and luminance are derived from candela through various photometric measurements including some homemade devices of laboratory. Direct traceability of the radiometer to the cryogenic radiometer gets an important advantage in the realization of photometric quantities with high accuracy. Bilateral comparison data of luminous responsivities of radiometers are also wanted to be presented if it becomes available until conference time.

5856-126, Poster Session

New method for real-time surface cleanliness measurement

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The measurement of the surface cleanliness is a problem of great importance in many industrial and technological processes. Existing methods are based on laboratory procedures, they are not performed in real time, they cannot be automated, and usually they are restricted to a small portion of the sample.

In this work we describe a new method for real time measurement of the amount of dirt deposited on a surface. It relies in the ablation of the dirt film by means of a short laser pulse and the subsequent measurement of the sound emitted. The intensity of the sound results proportional with the amount of dirt and provides a direct measurement of the cleanliness of the surface. We developed also a reference for calibration based in an uniform distribution of points printed on white paper or a transparent film. The density and the points size can be easily modified providing a homogeneous, uniform and reproducible standard for the total amount of dirt measurement.

Based on this method, we designed, patented (P000101241-Argentina and 6.546.784 EEUU) and developed the first industrial instrument (ELMES) for on-line determination of the cleanliness degree of manufactured cold rolled steel plate bobbins.

5856-128, Poster Session

Utilizing a TII aspherical measurement machine in a computer controlled polishing process

E. G. Pitschke, Fachhochschule Deggendorf (Germany)

The demand on quality of optical surfaces is increasing from year to year. Computer controlled polishing is one way to fullfill these demands. This process depends on measurements of the optical surface. In this paper the usage of the TII measurment machine is discussed to manufacture aspherical surfaces.

5856-129, Poster Session

The evaluation of particle counting efficacy of the new optical scattering method detecting the fluorescence for the particle number concentration standard in liquid

T. Sakaguchi, K. Ehara, National Institute of Advanced Industrial Science and Technology (Japan)

In order to establish a particle number concentration standard and the related calibration technology in liquids, a new particle counter based on the simultaneous detection of scattered light and fluorescence was examined. Sample particles from 2 to 10 micrometers in diameter were dyed. By making use of the fact that bubbles make no coincidence signals between scattered light and fluorescence on the other hand particles make coincidence signals, we could distinguish particles from bubbles. And we can establish the particle number concentration and the calibration technology in liquid. Using this system, fluorescence could be measured at 525 nm, 625 nm, or 675 nm as well as at 575 nm. To examine the electric counting error and error due to stray light counting, the four channels were compared. The difference in counting between each of the channels was less than 0.1% in relative standard deviation. To evaluate the reliability of the particle counts obtained with this system, the obtained values were compared with counts obtained using a microscope. With a microscope, the total area was manually scanned for the total counting to reduce the statistical uncertainty. The results of both methods were in good agreement, with a counting efficiency of 100% plus or minus 10% for 2 micrometer particles, and of 100% plus or minus 5% for 10 micrometer particles. The difference in the repetition of the new counter was less than 1%.

5856-131, Poster Session

Seismic Damage Identification using multi-line distributed fiber optic sensor system

S. Hou, J. Ou, Harbin Institute of Technology (China)

Structure seismic damage under a nondestructive earthquake can be evaluated by the maximum strain of the structure elements in the seismic response history, and a certain limit strain value would be reached in more than one structure element. In this paper, multi-line distributed fiber optic sensor system is designed for the requirement of multi-point damage identification of the structure. Optic fiber couplers are used to divide the laser into tow parts. With proper protection, one part light travels without power loss, and the other part of light will stopped at a point when the fiber is overloaded. An optical time domain reflectometer (OTDR) is employed for interrogation of the sensor signal. Experiment of beam flexural test is conducted, and experimental results are presented.

5856-132, Poster Session

Diffusion coefficient measurement of transparent liquid solutions using digital holographic interferometry

V. Chhaniwal, M.S. Univ. of Baroda (India); A. Anand, Institute for Plasma Research (India); C. S. Narayanamurthy, M.S. Univ. of Baroda (India)

A method to measure diffusion coefficient of transparent liquid solutions using digital holographic inteferometry is described. Holograms of a diffusively reflecting object through the experimental cell containing the diffusing solutions are recorded at different time instances. The recording medium is a CCD chip. The holographic interference of the object at two instances of time is numerically carried out in a PC and is used to determine the diffusion coefficient. Holographic interferometric fringes can be displayed on a PC monitor in near real-time. The diffusion coefficients calculated using this method matched very well with literature values.

The experimental setup is described as follows. Beam from a laser source is split into two. One of the beams acts as the reference beam. This beam is expanded and collimated. The other beam is expanded is allowed to fall on a diffusively reflecting object. This beam then passes through the transparent glass cell containing the experimental solutions. The object and the reference beams interfere at the CCD pane forming digital holograms. Digital holographic interferograms are formed by superposing holograms at two instances of time and digital reconstructions. These interferograms had two characteristic extremes. By measuring the distance between the two extreme points the diffusion coefficients could be calculated. For 0.5M ammonium dihydrogen phosphase solutions we obtained diffusion coefficient of 8.61x10-6 cm2/s, which is comparable with the literature value of 8.75x10-6 cm2/s.

5856-134, Poster Session

Pulsed Nd:YAG laser beam profile analyse.

H. Chmelickova, R. Ctvrtlik, H. Lapsanska, Palackˇ Univ. (Czech Republic)

Pulsed laser system LASAG with maximal average power 150 W is used in our laboratory for experiments with various kinds of materials,process parameters optimisation for cutting,welding, drilling and surface treatment.

Alignment of optical elements and good laser beam quality is critical parameter for successful result of laser treatment.Active medium in solid state laser is warmed up during laser action, because only some percent of input electrical power is turn to optical energy.Warm crystal has properties like a thick lens,which optical power is dependent on process parameters and kind of resonator. Also some defects in optical system - dirty or damaged mirrors or lens must be detect. Properties of non-visible near infrared beam can be tested by means of laser beam analysator SPIRICON that consists of sampler,attenuator,CCD camera and software to display information on monitor screen.In our system there are movable and changeable end mirrors and diaphragms to obtain six different types of resonators - basic one for welding and fibre applications and five ones for fine cutting and drilling.Measurements of beam profile for all these resonators were made with different values of pulse length,energy and frequency. Control of losses in optical system was made to inspect quality of optical elements.Measurement of laser beam output from three different fibre processing heads was realised.All data and captured pictures are stored and lessons for students in next school year were prepared.

5856-138, Poster Session

Birefringence measurement by use of digital holographic microscopy: examples with fiber optics and concrete samples

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In this paper, we present a modified transmission digital holographic microscope that can be used to image the state of polarization. The resulting device, called polarization digital holographic microscope, records in off-axis geometry the interference between two orthogonally polarized reference waves and the object wave transmitted by a microscopic sample and magnified by a microscope objective. A CCD camera records the resulting hologram. Using a single hologram, we can reconstruct separately the amplitude and phase of two wave fronts, which are used to represent the object wave's state of polarization, represented by the azimuth and the phase difference associated to the polarization ellipse. The proposed method is illustrated with two applications. The first application is to use a 10-times magnification microscope objective to measure the birefringence induced by internal stresses in transparent materials such as a bended optical fiber. We compare the azimuth and phase difference images obtained for the not bended and bended optical fiber. A uniform azimuth is imaged in the first case whereas the azimuth increases symmetrically from the center of the cladding region when the fiber is bended. The phase difference image of the not bended fiber shows a non-uniform refractive index in the cladding region because of the fiber internal stress due to fabrication process and the coating region has a phase difference of about 40°, due to the residual stress resulting from the winding of the fiber. In the case of bended fiber, the measured phase difference images of the entire optical fiber (cladding and coating) show as expected [F. El-Diasty, Interferometric determination of induced birefringence due to bending in single-mode optical fibers. J. Opt. A: Pure Appl. Opt 1, 197-200 (1999)], that the refractive index is modified only in the direction perpendicular to the fiber axis and is constant in the parallel direction. Furthermore, the horizontal refractive index increases for compressed areas and decreased for expanded area. The second application is to use a 20-times microscope objective to image the state of polarization of a thin concrete sample and reveal birefringent properties of the different aggregates found in the concrete.

5856-139, Poster Session

CCD based emissivity measurements for surface characterisation in heat treatment processes

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Plasma nitriding is an industrial surface hardening process which involves diffusion of nitrogen atoms into the metal surface and in this way to enhance material properties. In an atmosphere consisting of nitride and hydrogen plasma, nitriding takes place, whereas via a different mixture of

gas, the shaping of the coating layer can be altered. The aim of this work is the development of a low cost imaging device, based on a standard near infrared enhanced CCD camera, for the in-situ characterization of such surface modifications during the thermo-chemical heat treatment. Due to relatively low process temperatures of about 400°C - 600°C the received light intensity of the heated metal parts is very low. The imaging device therefore utilizes primarily the CCD-silicon's spectral sensitivity for wavelengths around 1µm. As the emissivity of metals generally increases strongly with shorter wavelengths, the considered spectral range has advantages with regard to sensitivity for emissivity changes (i.e. deviations from the greybody hypothesis). The measurement system is based on the principles of ratio pyrometry (dual-band-method), in which two images of the same scene, each taken in slightly different spectral bands, are used to determine the spectral light intensities. Additionally, image processing methods, based on multiscale analysis, which are adjusted to the noise characteristics of the CCD camera system, are incorporated. It is shown, that the exact characterization of the optical components (CCD camera, spectral filters) allows the theoretical modeling of the imaging process and the estimation of the spectral emissivity characteristics of different metallic surfaces. The imaging device and the results of the described method applied to various metal parts with different coatings are presented. The applicability of a multispectral CCD imaging device for correlating surface states with emissivity changes during industrial heat treatment processes is shown exemplarily.

5856-140, Poster Session

Method for measuring the complex refractive index of a turbid medium

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Based on the heterodyne interferometry and the effect of the total internal reflection (TIR), a method for measuring the complex refractive index (n + ik) of a turbid medium. In this method, a light beam coming from a heterodyne light source is incident on the interface between a right-angle prism and a turbid medium. If the incident angle is larger than the critical angle, the phase difference between s- and p- polarizations of the reflected light occurs. The phase difference depends on the incident angle and the complex refractive index (n + ik) of a turbid medium; their relation can be derived from Fresnel equations. The phase difference can be measured accurately with the heterodyne interferometry. Because there are two unknown parameters n and k to be estimated, at least the phase differences under two different conditions should be measured. Then, these measured data are substituted into the derived relation, and a set simultaneous equation is obtained. If the simultaneous equation is solved, the values of n and k can be estimated. Because the effect of TIR is used in this method, the scattering noises coming from the turbidity of the tested medium can be greatly reduced. In addition, this method has some merits such as simple optical setup, high sensitivity, high stability, and suitability for a little amount of the tested medium in its native state (without dilution).

5856-11, Session 5

Reflectivity function based illumination and sensor planning for industrial inspection

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Automation of visual inspection tasks is an important field of current research in industrial machine vision. Some of the key issues for a successful inspection process are suitable positions for the cameras and illumination devices. While several approaches for automatic sensor planning are available, interaction between illumination, inspected object and sensor settings is generally not considered. However, several settings of the camera, such as aperture and shutter time, directly depend on the amount of received light energy per pixel. Others, such as depth of field, indirectly depend on the received energy: low illumination levels generally require larger apertures and result in less depth of field. For inspection of several regions on highly non-planar objects this might e. g. imply the need for an additional camera for correct inspection.

The amount of received light energy per pixel directly depends on the bidirectional reflectance distribution function (BRDF) of the surface material of the inspected object and its geometry. While the latter is generally available through CAD models, reflectivity functions of arbitrary materials are often difficult to obtain. According to [Nayar], reflectance can be modelled as a function with a diffuse (Lambertian) component, a specular lobe and a specular spike.

In this paper, we will present a method to measure the BRDF of arbitrary materials. We will show how the reflectivity function can be used to derive the absolute amount of energy per pixel a camera receives. For several metallic materials common to industrial machine vision, we will show how to fit a reflectivity function model similar to the one described by [Nayar91] to the measured data.

We will then show how to extend an existing framework for automatic viewpoint selection [Ellenriederо5] to illumination planning. In this system, visibility of an inspected region of interest is determined by a spherical visibility map. We will show how to map the measured BRDF on the visibility map and derive a scalar cost function whose minimum determines a three-dimensional illumination position, from which a previously located sensor receives a desired amount of light energy. At the same time, the approach guarantees that the inspected areas are evenly illuminated resulting in optimal contrast. Additionally, we will show how to determine the internal settings of the sensor such as aperture, gain, and shutter time for appropriate exposure and depth of field .

The system is evaluated based on several real inspection tasks from current production processes.

References:

[Nayar91] S. Nayar, K. Ikeuchi and T. Kanade: "Surface Reflection: Physical and Geometrical Perspectives" ; IEEE Tran. Pat. Recog. Mach. Intel., Vol. 13, No. 7, July 1997, pp. 611-634

[Ellenriederо5] M. Ellenrieder and H. Komoto: "Model-based Automatic Calculation and Evaluation of Camera Positions for Industrial Machine Vision," to appear in Proc. SPIE Electronic Imaging 2005, Session Computational Imaging III

5856-12, Session 5

Illumination-based segmentation of structured surfaces in automated visual inspection

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We present a new method to segment images of structured surfaces from illumination series, i.e. sets of images of an object recorded with different lighting settings. We use a parallel light source, whose angle of incidence is described by the azimuth and the elevation angle. Depending on the surface topography, characteristic patterns are mapped onto the intensities viewed by the camera depending on the illumination direction. The segmentation itself is based on cluster analysis in a multi-dimensional feature space. The resulting classes correspond with the identified segments of the surface image. A crucial step within this approach is the definition of meaningful features. We focus on features that can be extracted from the signal described by the intensities at a single surface location depending on the illumination direction. We investigate features based on moments of this intensity signal as well as on its frequency decomposition with respect to the illumination direction. Furthermore, we show that features of this kind can be used to robustly segment a wide variety of textures on structured surfaces. In any case, since no spatial neighbourhood is utilized to compute the features, i.e. "averaging" takes place only in illumination domain, no spatial resolution must be sacrificed. Consequently, even very small regions can reliably be segmented, as is necessary when defects are to be detected.

5856-13, Session 5

New method of structure light measurement system calibration based on adaptive and effective evaluation of 3D-phase distribution

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In the paper a new method for scaling of phase values into (x,y,z) co-ordinates supporting methods with absolute phase determination e.g. fringe projection / Gray code techniques is presented. It is based on calculation of characteristic polynomials describing relationships between phase values and real (x,y,z) co-ordinates in measurement volume. Coefficients of these polynomials are calculated on the base of phase distribution on known 2D-calibration model positioned manually in several unknown positions inside measurement volume. It introduces new way of calibration by two step process. First, it calculates exact positions of model on the base of its phase distributions and secondly it evaluates coefficient of polynomials. Applicability of the method described is proven by calibration of 3D shape measurement system based on unknown, commercially available projection and detection systems with unknown parameters of imaging optics and geometrical set-up. Exemplary measurement results of technical and freeform objects are presented.

5856-14, Session 5

Mobile optical 3D sensor for industrial application

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A new mobile self calibrating optical 3D measurement system using fringe projection technique named "kolibri FLEX" will be presented. It can be utilised to acquire the all around shape of small to medium objects. The basic measurement principle is the phasogrammetric approach introduced by the authors /1, 2/.

The "kolibri FLEX" consists manly of two parts. The first part is the mobile sensor head made up of one fringe projector and normally two (or one) cameras. The second part is a rotation table with one or more cameras mounted on it. Automatic whole body measurement is achieved by using object rotation and changeable sensor head position, which can be done completely computer controlled. Multi-view measurement is realised by using the concept of virtual reference points /2, 3/. In this way no matching procedures or markers are necessary for the registration of the different images, which makes the system very flexible to realize different measurement tasks. Furthermore, due to self calibrating principle mechanical alterations previous to the measurement are compensated.

Typical parameters of the system are: the measurement volume extends from 100mm up to 500mm diameter, the measurement time is 2min for 12 images and the measurement accuracy is below 30µm.The flexibility and compact dimensions make the measurement system useful for a wide range of applications such as quality control, rapid prototyping, design and CAD/CAM which will be shown in the paper.

/1/ Schreiber W., Notni G.: "Theory and arrangements of self-calibrating whole-body three-dimensional measurement systems using fringe projection technique", Optical Engineering 39 (2000) p. 159-169

/2/ Kühmstedt P., Heinze M., Himmelreich M., Bräuer-Burchardt C., Notni G.:„Phasogrammetric optical 3D-Sensor for the measuremnt of large objects" Proc. SPIE 5457 p. 56-64

/3/ Notni G, Kühmstedt P., Heinze M., Himmelreich M. "Phasogrammetrische 3D-Messsysteme und deren Anwendung zur Rundumvermessung", Proc. der Oldenburger 3D-Tage 2003, Wichmann-Verlag, (2003) p. 21-32

5856-15, Session 5

Confocal micro-optical distance sensor: principle and design

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Increasing demands for checking tolerances of small mechanical and optical precision components require improved measurement techniques. In particular, components with a complex geometry such as small drilling holes or channels are difficult to access using state of the art tactile measurement systems. The advantage of optical measurement systems is that no mechanical forces occur during the measurement which could distort or displace a miniaturized sensor head.

In this Paper the basic concept and different optical designs of a confocal microoptical distance-sensor are presented. The sensors use the chromatic-confocal measurement principle, which has no need for a mechanical depth scan. Therefore, a chromatic-confocal point sensor can be designed without any moving parts. This is used to design a miniaturized sensor head with an outer diameter smaller than two millimeters. A special feature of the sensor head is its capability to measure sideways. This enables to measure surfaces in small drilling holes.

The new sensor concepts and optical designs will be discussed and the different optical elements will be presented. An diffractive element is used to achieve the necessary chromatic fan out of the light. Details of the production of the diffractive element will be given.

5856-16, Session 5

Confocal microoptical distance sensor: realization and results

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Increasing demands for checking tolerances of small and precise mechanical and optical components require improved measurement techniques. In particular, components with a complex geometry such as small drilling holes or channels are difficult to access using state of the art tactile measurement systems.

In this paper, the realization and characterization of a microoptical sensor concept using the chromatic confocal principle is presented. The sensor head is designed for distance gauging applications in high aspect ratio cavities with a diameter of about 2 mm. Focus will be on the fabrication process of the hybrid optical benches, which combine refractive and diffractive micro optical components. Very tight tolerances of the optical path are required for the functionality of the sensor. Therefore the alignment structures and mounts between the different optical elements are produced from PMMA using deep X-ray lithography, the first step of the LIGA process.

The new sensor concepts and designs, as well as accuracy of the structures and optical path will be discussed and measurement results of first prototypes will be presented. An outlook of possible application fields for these sensors in precision metrology will be given.

5856-200, Session 16

Dedicated near-field microscopies for electronic materials and devices

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With the ongoing reduction of structures sizes within any kind of electronic device inspection tools have to be used allowing a resolution of clearly below 50nm. This is not only necessary for a mere topological evaluation of the material or the device under test, but even more important for the nanoscopic determination of material parameters and device properties.

When using waves as probes for this purpose, near-field techniques are quite often the only means for overcoming the limitation in spatial resolution as due to Rayleigh's criterion, independently of the specific nature of the wave type used. In this manner acoustical and thermal waves can be applied for very high resolution testing as well as the well known scanning near-field optical microscope.

Moreover, such techniques are not limited to such simple systems in which the probing wave and the resulting interaction product are of same nature, like often in near-field optical microscopy, but more complicated systems may be suitable to gain the information needed.

In this sense near-field optical microscopy can be used for optical induced current measurements as well as for nanoscopic cathodoluminescence experiments, the evaluation of ferroelectric domains by polarization evaluation and the analysis of integrated silicon circuits by near-field photon emission microscopy are possible, too.

To achieve a more comprehensive information on the sample, results gained with one special technique can be compared with others, such as scanning thermal or acoustic microscopy. These allow determination of mechanical and thermal properties with the appropriate spatial resolution that can be compared - quite often simultaneously - with , for instance, optical and optoelectronic structures.

The necessary instrumentation will be described for those experiments with emphasis on the scanning near-field optical microscope. Examples for the application of near-field microscopies will be given for silicon technology as well as for compound semiconductors and functional ferroelectric ceramics. Usual electronic components like solar cells or light emitting devices will be treated as well as micro electro mechanical systems.

5856-17, Session 6

Influence of component imperfection on null ellipsometry with phase modulation

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A new null ellipsometer has been proposed that uses photoelastic modulator (PEM)

[1]. The phase modulation adds a good signal-to-noise ratio, high sensitivity, and linearity near null positions to the traditional high-precision nulling system. The ellipsometric angles Delta and psi are obtained by azimuth measurement of the analyzer and the polarizer—PEM system, for which the first and second harmonics of modulator frequency cross the zeros. In this paper we discuss influence of component imperfection on precision of null measurement.

Particular interest is devoted to azimuth angle error of compensator and modulator. Effect of residual birefringence of PEM is discussed. We show that the null system is insensitive to ellipsometer misadjustment and component imperfections and intensity calibration is not needed.

[1] K. Postava, A. Maziewski, T. Yamaguchi, R. Ossikovski, S. Visnovsky, and J. Pistora, Null ellipsometer with phase modulation, Optics Express 12, 6040-6045 (2004).

5856-18, Session 6

Compact electronic speckle pattern interferometer (ESPI) system using holographic optical elements (HOEs) and laser diode

S. R. Guntaka, V. Toal, S. Martin, Dublin Institute of Technology (Ireland)

Electronic speckle pattern interferometry using a holographic optical element (HOE) with a laser diode is presented. The use of a HOE in the ESPI system reduces the optical elements such as mirrors, lenses etc. The final system only consists of a laser, HOE, CCD camera and test object. Reflection holographic optical elements recorded on HP-650 silver halide emulsions with laser diode are used. The use of reflection HOEs produces the most compact ESPI system when compared with the transmission HOE based ESPI system. Vibration modes of circular aluminium plate excited using a paper cone loud speaker are presented. The current modulation of the laser diode is utilised to introduce the desired phase shifts. Amplitude and phase maps of the vibration mode pattern are reported.

5856-19, Session 6

Fiber optic spark plug sensor for UV-LIF-measurements close to the ignition spark

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Time-resolved observation of the fuel/air mixing process prior to ignition is crucial for the development of modern internal combustion engine concepts. The presented fiber optic sensor is designed for the acquisition of in-cylinder data in the area close to the ignition spark, based on UV-laser-induced fluorescence on organic fuel compounds. Excitation and fluorescence light are separately guided through silica fibers. The detection volume is defined by the optical design of the sensor head. Since the related components are completely integrated into a modified spark plug, the sensor can be applied to unmodified production line engines. We present the fundamental spectroscopic concept, the solution for the minimal invasive access through the spark plug and tracer spectra measured on a prototype.

5856-20, Session 7

Optical high-speed 3D metrology in harsh environments: recording structural data of railway lines

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No abstract available

5856-21, Session 7

Absolute distance interferometry for space interferometers

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Future space missions, among which the Darwin Space Interferometer, will consist of several free flying satellites. A complex metrology system is required to have all the components fly accurately in formation and have it operate as a single instrument. Our work focuses on a possible implementation of the sub-system that measures absolute distances with high accuracy. For Darwin the required accuracy is on the order of 70 μm over a distance of 250 meter.

We are exploring a technique called frequency sweeping interferometry, which involves interferometrically measuring a phase difference while sweeping the wavelength of a tunable laser. This phase difference is directly proportional to the absolute distance. As a reference standard we use a very high finesse Fabry-Perot cavity, to which we lock the laser at the endpoints of the sweep. We will discuss the control system that drives the setup and show some first experimental results. We also show that under benign conditions we can use only one laser, where usually two lasers are used to compensate for movement errors.

5856-22, Session 7

An online laser caliper measurement for the paper industry

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A non-contacting online caliper measurement has been papermakers' dream for over two decades. Currently, paper thickness is measured using buttons contacting the paper web on both sides. In such a configuration, paper thickness is assumed to be the distance between the contacting surfaces and determined by an magnetic measurement principle. However, this arrangement of contacting measurement has several disadvantages including sheet marking, hole creation, dirt build-up on the contacting buttons, wearing of the contacting surfaces, and even sheet breaks. Moreover, the current trends in paper manufacturing, especially the increasing use of recycled raw materials are necessitating the development of a more reliable thickness measurement solution that is not effected by dirt and other material on paper or board sheet surfaces.

So far, a non-destructive, on-line thickness measurement has not been successfully applied in paper production environment. Recently, Metso Automation has successfully piloted in several mills a caliper sensor that does not contact the sheet on both sides and is able to measure paper thickness with sub-micron accuracy. The new sensor is based on single sided laser triangulation. This paper presents the measurement set-up and discusses the challenges encountered. Measurement results obtained in mill trials with various paper grades are reviewed and compared to those made simultaneously with contacting, on-line sensors and off-line laboratory results of the same sheet. Factors affecting the measurement with conventional and optical thickness sensors are also discussed.

5856-23, Session 7

Robust high-precision 2D optical range sensor

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This contribution describes an intelligent and robust 2D optical range sensor which aims at high precision distance measurements as required in quality control (QC) measurements on a large cylindrical structure. The sensor combines structured light (laser projector) and 2D image acquisition to measure the relative position of the object under test with respect to its local reference coordinate system. The sensor is calibrated in a two-step process: A special target is used to calibrate the camera and projector geometry. The on-site adjustment involves the calibration of the relative orientation w.r.t. the measurement object. A robust signal processing scheme is used to extract the 2D range information out of the speckled images. In order to obtain reliable sensor readings in industrial environments two steerable matched filters are applied. The standard deviation of the measurement result is drastically decreased using model based line estimators. Based on prior knowledge of the surface geometry of the unit under test the sensor is able to estimate its pose with respect to a local reference coordinate system. The sensor delivers 2D displacements at a rate of 30Hz with an accuracy of ±0.01mm.

In an industrial application we use two of the above described 2D range sensors to control the quality of a cylindrical structure during the manufacturing process. Based on the 2D range sensor readings a robust DFT estimator delivers highly accurate estimations of the desired geometrical parameters of the unit under test.

5856-24, Session 7

Optical distance measurements for closely spaced targets using a FMCW approach

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Optical time-of-flight (TOF) distance measurement systems are used in many industrial and military applications. One advantage of optical systems is their ability to obtain measurements without contact. Depending on the modulating signal, pulse- or continuous wave modulation, various methods exist for estimating the TOF. In contrast to microwave radar systems where the carrier frequency is modulated, in optical systems the intensity of the laser beam is modulated. In this paper an optical FMCW (frequency modulated continuous wave) distance sensor is proposed. A measurement acquisition system is realized from which the real data are collected. Additionally a simulation of the system is performed. One advantage of FMCW is its multi target capability, what means two or more axial targets can be detected and their absolute locations or their displacement can be measured. The proposed sensor is used for measurements in multi-target scenarios. A simple signal model is tested and verified using both simulated and measured data of the distance sensor. According to this signal model a distance estimation procedure is introduced. The FMCW-method either extracts the signal parameters from the instantaneous frequency signal in frequency domain using the FFT, or by the eigenvalues of the correlation matrix using the MUSIC (multiple signal classification) algorithm.

A verification of the theoretical description for FMCW-systems by the corresponding real measurements has not been previously accomplished. Simulation results obtained from synthetic data generated according to the signal model are compared to measurements recorded from a real FMCW distance sensor. For both cases the measurement accuracy is analyzed. Therefore stochastic errors and systematic errors are separated. The variance of the measurements is close to optimal, if the FFT-approach is used. The stochastic error follows the Cramer-Rao bound, which is a lower bound for the variance of the estimations. If the MUSIC approach is used, the variance is higher. However, there is a tradeoff between the two approaches. For closely spaced targets the resolution is given by the minimum distance between two targets, for that the two targets can be detected. The resolution of the FFT approach follows from the equivalent wavelength of the signal bandwidth. The resolution of the MUSIC approach falls below this border, as it is a subspace method. At least the systematic error, also called bias, is investigated. Again it depends on the distance between the targets which approach yields the better accuracy. If using the MUSIC approach the systematic error is smaller for closely spaced targets. On the other hand the error decreases faster with increasing target displacement, if the FFT approach is applied.

In this paper a FMCW distance sensor is investigated. The estimation results of real measurements are compared to simulated measurements with synthetic data. According to the good agreement, it can be concluded that the distance sensor is accurately modeled. Furthermore, a performance comparison reveals that, for the considered settings, the achieved measurement accuracy of the real system can be precisely predicted from simulations.

5856-25, Session 7

Profiling of gas turbine blades using phase shifting Talbot interferometric technique

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Optical three dimensional (3D) non-contact profilometry has been widely used for various applications like 3D sensing, machine vision, intelligent robots control and monitoring of industrial products. Several 3D profilometric methods those make use of structured light pattern, including moiré technique, interferometry, phase measuring profilometry, FT profilometry, modulation profilometry, spatial phase detection, laser triangulation method, colour coded fringe projection and gray coded binary fringe sequences methods, have been already developed. Out of these methods phase shifting grating projection moiré topography, active phase shifting interferometry, FT profilometry, phase shifting digital holographic interferometry and Talbot interferometric techniques are becoming useful tools for precision measurement and profiling in research laboratories and industries.

Fringe analysis by peak detection and fringe order determination is tedious and time consuming. Using phase shifting interferometry the interferograms can be analysed automatically and this information from interferograms can be extracted with higher sensitivity and accuracy.

In this paper we present phase shifting Talbot interferometry for measurement of surface topography of gas turbine blades. Interferograms of different steps are recorded and displayed on computer monitor using digital techniques. Presence of harmonic components in phase map due to Ronchi gratings are removed by using Fourier filtering. The variation of surface height at different points of the objects is obtained by generating phase map. The results obtained by phase shifting Talbot interferometric techniques are in good agreement with that of measured by the manually controlled co-ordinate measuring machine. The critical analysis of results alongwith error analysis is presented

5856-26, Session 8

Measurements from a novel interferometer for EUVL mirror substrates

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A previously reported interferometer without intermediate optics is used to perform measurements on an aspherical extreme ultraviolet lithography mirror substrate. Acousto-optic modulation based phase shifting is used together with a novel phase retrieval algorithm to retrieve the phase distribution from our interferograms. The phase distribution is then processed by a previously reported inverse propagation algorithm to give the shape of the mirror under test. Our results are compared with measurements performed with conventional Fizeau interferometry and the discrepancies are discussed with reference to systematic error sources inherent in the classical and novel interferometers.

5856-27, Session 8

Improved optical linewidth measurement by means of alternating dark field illumination and model-based evaluation

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The dark field microscopy method with alternated grazing incidence illumination (AGID), which was developed at the PTB, offers the possibility of the measurement of lateral structures below the classical resolution limit. Besides this method offers the advantage for a better dimensional measurement of phase objects, since one receives a higher contrast than with conventional bright field microscopy. For example, the AGID-method can be used for the determination of the measurement of linewidths on photomasks or wafers.

A newly developed prototype on the basis of the alternating dark field illumination will be presented. This system uses as lightsources two diode lasers at 375 nm. This new system is compared with the conventional bright field microscopy. The image of a given structure depends on the illumination and the material parameters as well as the optical parameters. In particular the dependence on the polarization and the angle of incidence of the illumination will be discussed.

For modelling of the intensity distribution in the image we are using two different rigorous grating diffraction theories. On the one hand we use for calculation of the diffracted electric and magnetic fields the rigorous coupled wave analysis (RCWA) method and on the other hand the finite elements (FEM) method. Both methods are adapted to the prototype system and will be compared. Among other things the possibility of determination of edge angles of the lines will be discussed.

These two models are used, in order to evaluate the linewidth from measurement data of the new prototype. It will be shown that the newly developed prototype is a good tool for a better optical linewidth measurement and represents a meaningful addition for existing optical linewidth measurement systems.

5856-28, Session 8

Mirror shape detection by "Reflection Moiré Method" with optical design validation

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Shape detection on objects of large and huge dimensions has always represented a challenging task, mostly by the practical point of view due to the size of the related measurement equipment. When the tested object is a mirror the measurements is additionally complicated, since the classical techniques of structured light cannot be directly applied. The method proposed in this paper has been applied to measure the curvature of a deformable mirror of 1-meter diameter for a heliostat plant. The mirror shape is obtained studying the spatial variations of a grating projected on the sample and reflected by it on a screen. The measurement set-up employs a PC projector and a digital camera. The results of this curvature assessment are compared to those derived from a simulation obtained by an optical design programme.

5856-29, Session 8

High-accuracy profile form measurement by a scanning system of a slope and coupled distance sensors

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A scanning system of a slope and coupled distance sensors is proposed for high-accurate profile form measurement of optical surfaces. The system allows to estimate first order scanning stage errors as well as systematic errors of the distance sensors. Additionally, high resolution is achieved.

The scanning system is moved along the surface under test at equidistant steps and it is designed such that redundant information of the topography profile emerges. This allows for the additional estimation of first order scanning stage errors as well as systematic distance sensor errors. All unknowns may be simultaneously estimated by application of least-squares.

In particular for large surfaces measured with high resolution the computational burden of the overall least-squares solution can be high and computational aspects are discussed. Furthermore, the impact of the design of the sensor system and the choice of the measurements is treated with regard to resulting uncertainties of the least-squares solution.

5856-30, Session 8

Industrial inspection of specular surfaces using a new calibration procedure

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No abstract available

5856-31, Session 9

High-speed and line-feed Fourier domain optical coherence tomography

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No abstract available

5856-32, Session 9

2D parallel optical coherence tomography and multiple-layer information extraction

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During the past decade, optical coherence tomography (OCT) has been vigorously developed into a powerful tool for biomedical diagnosis applications. Because this technology has the nature of extracting the internal features of an object, its applications can be extended to document security, biometrics identification, and industrial inspection. In addition, its high imaging resolution makes OCT an ideal tool for massive storage/retrieval of 3D data. In this paper, we propose the 2D parallel OCT system and its application for multiple-layer information retrieval. We will study the issues that exist exclusively in this type of application, such as interlayer phase/intensity modulation and the parasitic fringe patterns resulting from the surfaces of the information layer. The basic procedure of the proposed OCT system includes three steps: 1) extraction of cross-section raw images at each layer of an object; 2) removal of the interfering

fringes by algorithm derived from multiple phase-shifted images; 3) elimination of interlayer modulations and parasitic patterns. Other issues that may degrade the retrieved images are also discussed. The simulation results and experimental tomography obtained from different testing samples are presented and discussed.

5856-33, Session 9

White-light spectral interferometric technique used to measure the dispersion of the group birefringence of a uniaxial crystal

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A new spectral-domain interferometric technique employing a simple experimental setup is used to measure the group birefringence of a uniaxial crystal of known thickness over the wavelength range of the visible spectrum. The experimental setup comprising a white-light source, a Michelson interferometer, a polarizer, a uniaxial crystal, an analyzer, and a low-resolution spectrometer is utilized to record a series of spectral interferograms for different optical path differences (OPDs) adjusted in the Michelson interferometer. The spectral interferograms include interference fringes resolved only in a narrow spectral range around the so-called equalization wavelength at which the overall group OPD between interfering beams is zero. We measure the equalization wavelength as a function of the OPD in the Michelson interferometer to obtain directly the wavelength dependence of the group birefringence of a calcite crystal. Using the calcite crystal of two different thicknesses, we confirme that the measured dispersion of the group birefringence agrees well with the theoretical one. The thicknesses of the calcite crystal are also determined precisely from the slopes of linear dependences of the measured OPDs on the theoretical group birefringences.

5856-34, Session 9

Dispersive white-light interferometry for thin-film thickness profile measurement

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Dispersive white-light interferometry generally represents an approach of generating the spectral distribution of interferograms directly by means of dispersive optics without mechanical scanning between the objective lens and the target surface. The interferogram produced from a given fixed optical path difference is dispersed by using a spectrometer to obtain its spectral distribution directly in real time. This dispersive approach allows for high-speed implementation of surface measurements through a single capture of interference signals, and offers high immunity to external vibration encountered during measurement.

In this paper, we propose a new scheme of dispersive white-light interferometer, which aims to perform two functions of measuring the surface height profile and the thickness of thin film layer of the target surface at the same time. For the two-fold mission, a polarizing Michelson interferometer is used with a beam of white light generated from a tungsten halogen lamp, in which the target surface and the reference mirror are illuminated with different orthogonally polarized components, respectively. The detection part consists of two separate spectrometer units; one is for collecing the self-interference signal generated only by the multi-reflection occurred within the thin film of the target surface. The other detector captures the interference of the two waves from the target and reference mirrors. Experimental results prove that the new method of white-light interferometry is suitable for in-situ applications of surface height profile or thin film thickness measurements for industrial applications.

5856-35, Session 9

Full-field optical coherence topography with a direct Read-out CMOS camera

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A comprehensive characterisation of a complementary metal-oxide semiconductor (CMOS) and digital signal processor (DSP) camera, used typically in machine vision applications, is presented in this paper. The camera consists of a direct read-out CMOS sensor, each pixel giving a direct analogue voltage output proportional to light intensity, with an analogue-to-digital converter and digital signal processor on the back-end. The camera operates as a stand-alone device using a VGA display; code being pre-programmed to the onboard random access memory of the DSP. High detection rates (kHz) on multiple pixels were achieved, and the relationship between light intensity and pixel response time was quantified. The CMOS sensor, with 1024x1024 pixels randomly addressable in space and time, demonstrated a dynamic logarithmic light intensity sensitivity range of 120dB. Integrating the CMOS camera with a low coherence a Michelson interferometer, full-field optical coherence topography images of a rough aluminium 100μm step profile have been acquired. The intended application is an imaging device for simple yet functional full-field optical coherence tomography (OCT). The advantages of the CMOS sensor are the potential for carrier-based detection, through the very fast pixel response with under-sampling, dynamic region-of-interest imaging at high frame rates, and the elimination of the electromechanical lateral scanning of conventional OCT by replacing it with electronic pixel scanning.

5856-36, Session 10

Micro-optics metrology using advanced interferometry

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Interferometric testing of micro-optical components involves some challenges due to problems such as Fresnel diffraction artefacts, the non-common path interferometer configuration, coherent noise as well disturbing interferences, and uncertainties in distance measurements. Recently we have developed a versatile Mach-Zehnder / Twyman-Green hybride interferometer for micro-optics testing. The system combines the advantages of both interferometer types and allows full characterization of lens and surface figure errors as well as radius of curvature and focal length measurements. The interferometer system is explained and measurement results of micro-lenses are presented. In particular, this paper is concerned with the metrology challenges of interferometric testing on microscopic scales.

5856-37, Session 10

Microlenses metrology with digital holographic microscopy

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Digital holographic Microscopy (DHM) is an imaging modality reconstructing the wavefront in a numerical form, directly from a single digitalized hologram. It brings quantitative data derived simultaneously from the amplitude and phase of the complex reconstructed wavefront diffracted by the object and it is used to determine the refractive index and/or shape of the object with accuracy in the nanometer range along the optical axis. DHM comprises a microscope objective to adapt the sampling capacity of the camera to the information content of the hologram.

This paper illustrates some of the possibilities offered by DHM for micro-optics quality control. Kebbel et al already obtained some results in this field (V. Kebbel, J. Muller, and W.P.O. Juptner, "Characterization of aspherical micro-optics using digital holography: improvement of accuracy," Interferometry Xi: Applications, 4778, 188-197 (2002)) with digital holography in a two wavelengths configuration without objective lens, needing a 15 frames averaging for an up to 283 nm axial resolution obtained with a cylinder lens. Actual results obtained by DHM, yielding an axial precision up to 3.7 nm, will be compared with measurements performed with interferometers by SUSS MicroOptics SA and with the profiles measured with a mechanical scanning probe instrument (Alpha step 200 from Tencor Instrument).

Compared to classical phase shifting interferometry used as a standard in micro-optics quality control, DHM offers similar performances in terms of resolution, precision, repeatability and field of view, and has in addition three main advantages. First measurements are performed much faster, as the complete description of the complex wavefront is obtained from a single hologram capture, while at least three acquisitions are required with phase shifting techniques. This results in a drastically reduced sensitivity to external perturbations (vibration and ambient light), since the capture time is reduced to a few microseconds. Secondly the accuracy of the apparatus is not intrinsically limited by the precision of the control of moving parts, as DHM is exempt of it. Thirdly the original numerical procedures of DHM for automatic wavefront corrections enable a simplification of the optical design. The theoretical basis of this feature will be exposed and illustrated by examples. This numerical procedure enables DHM to investigate any microlenses form, also cylindrical or strong aspherical microlenses, with the same ease of use and performances as with spherical lenses, what is difficult or quite impossible to manage with a classical Twyman-Green (TWG) interferometer.

Two different arrays where tested: a quartz refractive lenses array (observed with transmission DHM) and a Silicon refractive lens array (observed with reflection DHM); they where investigated by the DHM, the Alpha step and the interferometry techniques (realized at SUSS MicroOptics SA). The radius of curvature (ROC) is for example measured and differences in the measured values are much lower than 1% (quarz lens ROC: 349 mm with TWG, 351 mm with DHM; Si lens ROC: 1662 mm with TWG, 1662 mm with Alpha step and 1660 mm with DHM).

Actual axial precision is 4.1°, i.e. 15.8 nm (lambda/40) in a quartz sample in the transmission setup and 3.7 nm (lambda /175) in the reflection setup. The axial maximal resolution reach 1.8 nm for quartz (lambda /355) in transmission and to 0.4 nm in air (lambda /1565) for the reflection system. With a PC, 3D phase reconstruction rate is 15 frames/second, making DHM an ideal solution to proceed to systematic investigations on large volumes of full wafers of micro optic samples.

5856-39, Session 10

Development of measurement of micro-structure using moiré topography in SEM.

Y. Arai, Kansai Univ. (Japan)

In this paper, moiré topography method for 3D shape measurement of micro structure like a mems is proposed by using scanning electron microscope(SEM) based on reflective electrons. The measurement system is constructed with SEM and a grating produced by silicon processing of the mems technology by the similarity in the optical system of moiré topography. Moire fringes by electron beam can be observed for flat plates and sphere surfaces just like ordinal optical moiré topography in this system. A new measurement method for micro structure is developed using the phenomena. The principle of this method is investigated in experiments concerning in the measurement of the slope of a plane. Then, the validity of the method is confirmed in the experiment using the grating whose pitch is 400 micrometer. Furthermore, the possibility of expansion of the method as a future technologies and current problems are discussed.

5856-40, Session 10

Edge enhancement of week-phase object in laser scanning confocal microscope

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In the image of laser scanning confocal microscope, an edge of a weak phase object is sometimes enhanced as bright and/or dark line. This phenomenon is thought to be caused by the interference effect of diffractive light from the edge. The imaging characteristics of this type of microscope are regarded as a product of the optical sectioning characteristics (I-Z response) and the optical property of its imaging system. The I-Z curve decreases monotonically with depth (Z) which is determined by a diameter of pinhole and a numerical aperture (NA) of imaging system. Analyzing partially coherent imaging system under the weak phase approximation, we found that intensity image generated with increasing a defocus in observing weak phase only object of step-like figure. Accordingly the peak in optical transfer function (OTF) arose at some point of specific defocused depth in response to the spatial frequency of an observing object, so we observe an edge enhancement in this type of microscope. In experiment, we used OLS1100 laser scanning microscope (Olympus Co., Ltd.) with NA=0.95 in 100-power objective. Light source is Ar-ion laser of 488nm. We prepare rectangular samples which have 5.0 micron in width, and 50 nm in depth. We observed edge enhancement in auto-focus mode for the above samples. After measuring defocus characteristics of I-Z response we evaluate our theory in good agreement for the edge enhancement on the image of laser scanning confocal microscope.

5856-92, Session 10

Liquid mirror as planarity standard: a simplified experimental approach

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Planarity measurements are usually performed comparing the test surface with a reference flat. In turn, the calibration of the reference flat takes place at Institutes and Centers accredited in the sense of legal metrology. Due to the high level of accuracy required, reference flats are typically made of fused silica and are calibrated by interferometry, using absolute methods such as the classical three-flat test.[1, 2] In our laboratory we use a variant of the latter test, achieving a measurement uncertainty of 0.5 nm peak-to-valley (2 sigma) over a diameter of 94 mm [3, 4]. A problem that remains, however, is the validation of the test itself, to be achieved by interlaboratory comparison ("round robin"). Round robins on planarity are though infrequent [5]; in their absence, we have developed a simplified version of the liquid mirror test [6-8], easy to be implemented in a metrology facility equipped with a programmable interferometer.

In this paper we discuss the use of a liquid mirror as a way to generate a planarity standard for legal metrology. After that, we have used it to calibrate our silica flats, comparing the planarity values so obtained with those obtained with the three-flat procedure. We report details of the method, and discuss the experimental results.

5856-41, Session 11

Dimensional metrology for the fabrication of imaging optics using a high-accuracy low coherence interferometer

R. C. Wilhelm, A. Courteville, FOGALE nanotech (France)

This paper presents a fibre-based low coherence interferometric sensor developed by FOGALE nanotech. Based on the well-established principle of low

coherence interferometry the sensor works as a comparator of optical path lengths. The optical path length in the measurement interferometer arm containing a target object is compared with the optical path length in an internal delay line. Multiple, partially reflecting surfaces of the target can be detected during one scan of the delay line.

Measurement ranges are between a few mm up to 50 cm. The measurement zone can be placed at a distance of up to several meters away from the instrument's exit. The sensor reaches an absolute accuracy down to +/-0.1 μm over the full measurement range. The system has been applied both for the glass and for the optical industry. This paper focuses on innovative applications of the sensor in the optics manufacturing industry.

First, the measurement technique and the system concept including the detection scheme and signal processing are explained. We present a modeling-based approach for the dimensional metrology of optical components (e.g. single lenses, windows, prisms) or complete lenses where the positions of all individual elements can be detected. A comprehensive propagation model including dispersion and phase effects is used to extract the distances from the optical path differences. Prior to a measurement, the optimum tailoring of the measurement beam is obtained by a simulation of the beam propagation through the target object. This ensures that each surface to be measured delivers a sufficiently strong signal. To illustrate our approach we present its successful application in the fabrication process of high-performance imaging optics.

5856-42, Session 11

A long standoff profilometer for surface inspection in adverse environments based on conoscopic holography

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On-line dimensional control of 100% of the production, including surface defect detection, is becoming a key factor for the competitiveness of modern industries, being an important step for systematic homogeneous inspection, fast process feedback and process knowledge among others. The requirements of low cost, easy setup, applicability in adverse environments (normally along the process line), versatility and reliability pose a great challenge for the metrology science.

Conoscopic Holography has proven to be suitable for this purpose, offering high precision profile measurements with a wide range of working distances. This paper shows the current developments at the University of Oviedo in close collaboration with Optimet, owners of the patent of this technology, for a conoscopic sensor able to obtain a distance profile of a target in a single scan while working at long distances, keeping a good relation between resolution and stand-off. Typical values are 0.1 mm resolution at 700 mm distance. Using this sensor and the appropriate software, surface defects such as scratches, pores, lacks of material, form defects or adherences can be reliably obtained over a great variety of materials and surface configurations.

The first part of the paper discusses the working principles of Conoscopic Holography and shows the sensor set-up. Distance information is obtained in a fringe pattern in which the density of the fringes is related to the distance of the light emitting point. By obtaining the frequency or phase of these fringes, it is possible to estimate the distance to each of the points that are illuminated by the laser line. Necessary algorithms for obtaining this information are presented and the whole process is illustrated with real captures of different test objects.

The second part extensively focuses on a real example of this technology applied in an on-line inspection system in steel continuous casting funded by the European Committee for Steel and Carbon and which is currently working in Aceralia LDA steelmaking factory in Asturias (Spain). This system is placed in the process line and performs on-line detection of surface defects such as cracks over hot (above 700^{0}C) steel slabs from a distance of 1200 mm, to decide if they need any reparation before they are sent to the next process. 100% of the production is inspected without interfering with the process and without adding any delay.

Finally the paper discusses potential problems and limitations, such as the high levels of inherent speckle noise or the speed of operation (currently at 30 frames per second) as well as future improvements and suggested fields of application.

5856-43, Session 11

3D surface reconstruction based on combined analysis of reflectance and polarisation properties

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In the domain of industrial quality inspection, 3D reconstruction of surfaces is often performed by photogrammetric techniques such as projection of structured light. Although these active approaches are very accurate, their complexity with respect to setup and calibration is high, and they are often too time-consuming for inline quality inspection tasks. The same is true for surface analysis methods based on microscopy or interferometry.

An image-based framework for quality inspection of surfaces based on 3D surface reconstruction by self-consistent fusion of shading and shadow features is presented by Hafezi and Wöhler 2004. This method requires standard cameras and lenses for image acquisition, and the smallest detectable depth differences amount to less than one tenth of the pixel resolution, measured in the original image scale. The accuracy of reflectance-based methods, however, significantly decreases for surfaces with a strong specular reflection component, as the specular reflectance behaviour is difficult to model and may eventually lead to highly ambigous reconstruction results.

For many materials, surface regions displaying strong specular reflection exhibit polarisation effects. Upon reflection, unpolarized light is partially linearly polarised. The polarisation effect is particularly strong for the specular reflection component, while diffuse reflection causes weak polarisation effects. The degree and the direction of polarisation depend on the surface orientation, surface roughness, light source position, camera position, and surface material, but not on surface albedo. Previous work by Wolff and Boult 1991 and Rahmann 2001 has utilized polarisation analysis for edge and material classification, for separation of reflection components, and for surface reconstruction.

In this paper we present a novel surface reconstruction algorithm that incorporates both shading and polarisation features into a single variational framework. We show that this combined approach strongly reduces the ambiguity of the surface reconstruction result encountered when applying techniques based on shading or polarisation alone. An error functional consisting of error terms related to measured shading and polarisation properties is minimized (cf. e. g. Horn 1989) in order to obtain a 3D reconstruction of the surface. Shadow features can be incorporated into the algorithm as described by Hafezi and Wöhler 2004.

Most previous work has focussed on smooth dielectric materials, for which simple physical relations describing the polarisation properties of light reflected from the surface are valid - they are determined by the index of refraction and dielectric constant. Our application scenarios, however, are dealing with rough metallic surfaces such as forged or cast iron, for which no adequate model description exists so far. Therefore we have measured the polarisation properties using a goniometer stage along with a linearly polarising filter mounted in front of a standard greyscale camera. Our experiments carried out on synthetic and real scenes show that the presented combined approach yields promising results even in cases which are intractable for methods based on shading or polarisation alone.

5856-44, Session 11

Computer generated holograms for the optical shop testing of aspheres

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With computer generated holograms (CGH) the testing possibilities of interferometers for plane and spherical specimen is widened to the test of aspherical surfaces. The wave from a transmission flat or a transmission sphere is formed by the CGH to fit the surface of an asphere or a cylinder. The availability of suitable CGHs is often the limitation for the production of precision aspheres. JENOPTIK L.O.S. can provide a custom made CGH within a short time. We will show the design principles and the layout of the CGHs. The optical properties and the known limitations will be presented on the basis of measurements of aspherical surfaces.

5856-45, Session 11

3D measurement of human face by stereogrammetry

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At present are adapted several methods for optical characterization of 3-D surface profiles and forms, which are based on fringe projection, moiré techniques, gray-code projection or photogrammetry. According on method and application the advices differ in accuracy, measurement as well as computation time or its constructional complexity.

Photogrammetry is a well adapted method for measurement of 3-D objects. The basic idea of the method is to get the whole 3-D matrix of real objects by capturing a number of 2-D images. The captured images contain information to calculate the third dimension by itself - if the image is well structured by intensity - or by a special illumination.

In this work we show a possibility for a rapid measurement of the shape of a human face for medical applications (e. g. jaw-measurement). Often children are the objects of such examinations - that's why the main aim is based on decreasing the time of measurement.

The surface structure of the human face is too homogenous to find homologous points by an ordinary illumination; therefore special statistical patterns are projected on the face. About 20 pictures are taken by each camera of the convergent stereo system. To find the corresponding points in the pictures we use an enhanced correlation technique, which takes all pictures into account in one step. Consequently the 3D surface points can be reconstructed. Up to the present no object information is considered, so that other objects could also be measured.

Depending on imaging hardware (cameras and interfaces) it is possible to realize a time of measurement less than one second. The reachable accuracy is +/- 0.1mm, which is sufficient for medical and other applications.

5856-46, Session 11

Precision inspection of diameters for circular reflecting cylinders

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Precision noncontact measurement of diameters of circular reflecting cylinders is an actual problem in industry, especially under inspection of rollers of frictionless bearings with their diameters up to 50 mm with measurement error no more than 0.5 μm.

Optoelectronic methods are promising for such type of measurements and unlike known capacity and induction methods are more stable under external electromagnetic fields and are not affected by material parameters of inspected object. Measurement of large diameter objects by well-known interference method [1] often requires the use of optical systems with significant magnification for interference pattern recording (due to its small size) under CCD array recording. It is resulted in increase coherent noise and leads to errors of some microns.

We have developed differential Fraunhofer diffraction method, which is appropriate for measurement of large diameters (several millimeters and more). Peculiarity of this method is rather measurement of gaps between two cylinder vertexes and two reference half-planes, than measurement of cylinder diameter by direct Fraunhofer method. We have used the reference half-planes with out-of diametrical object position (instead of diametrical plane position in [2]) that allows to reach the high sensitivity of method without close approach to the surface of the inspected object. It decreases the probability of reference half-planes damage due to their contacts with cylinder in some emergency cases. Diffraction field is formed by free space instead of Fourier objectives which makes it possible to obtain significantly greater measurement accuracy.

Equivalent model for formation of Fraunhofer diffraction pattern by measurable object is presented. The proposed algorithm for processing of two diffraction patterns from gaps between cylinder vertexes and reference half-planes allows to determine objects diameter with inaccuracy of one-half micron. Experimental results are given.

5856-47, Session 11

ESPI for contouring of surfaces with discontinuities

A. Purde, N. Werth, A. W. Koch, Technische Univ. München (Germany)

Electronic speckle pattern interferometry (ESPI) can provide accurate contour measurement in the micron range and short measurement times far below one second. An advantage of this method is that illumination axis and observation axis can be identical in contrast to e.g. triangulation. Therefore ESPI represents an interesting alternative to other optical measurement principles used for surface profiling. Typical surfaces in industrial applications often show discontinuities, like steps or holes. An unambiguous measurement of such surfaces is only possible if the synthetic wavelength is chosen larger than the largest surface step. A high synthetic wavelength, however, introduces a high noise level such that an unambiguous measurement combined with a high accuracy is not possible in any case. The solution for this problem is the combination of two or more synthetic wavelengths. In contrast to other publications (hierarchical, pixel-wise approach) our novel area-based approach uses only two synthetic wavelengths minimizing measurement time and device complexity. The use of areas instead of pixels allows a lower signal to noise ratio and a smaller number of synthetic wavelengths (in our case only two) respectively, compared to the hierarchical pixel based approach. In this paper we present the steps required during pre-processing (laser tilt and wave front compensation) and the opportunities and drawbacks of different algorithms used for the fusion of the two images gained from different synthetic wavelengths. The data used for fusion suffers from a

high noise level what makes an effective noise filtering to an essential part of the fusion. The noise filtering and the consequent steps of the fusion will be evaluated in terms of error-rate, resolution and contour accuracy.

5856-59, Session 12

Performance evaluation of a residual stress measurement device using indentation and a radial in-plance ESPI interferometer

A. Albertazzi Gonçalves, Jr., R. Sutério, Univ. Federal de Santa Catarina (Brazil)

Residual stresses are present in most manufacturing processes. They are particularly critical in welding, forging and casting. The knowledge of the residual stresses level is very important to predict fatigue life and for the assessment of the safety level of a mechanical part or structure. In practice residual stresses measurement is a highly consuming task that requires skills and experience of a technician. It is highly desirable a more practical way to measure residual stresses.

A new kind of electronic speckle pattern interferometer (ESPI) has been developed by the authors' group using conical mirrors to achieve radial in-plane sensitivity. In this paper this radial in-plane (RIP) is used in combination with the indentation method to measure residual stresses in metals. A controlled indentation print is applied to the surface of the specimen by a diamond tip. As a consequence, a local yielding is developed and the material on the specimen surface moves away from the indentation print. The amount of the radial displacement component around the indentation print is strongly influenced by the level and direction of residual stresses state acting in the specimen. It is accurately measured by the RIP interferometer and fitted to a mathematical model.

A portable device using this technique was built to measure residual stresses in filed conditions in few minutes. It integrates a measurement and an indentation heads. The performance of the portable measurement device is evaluated through a set of controlled experiments. The amount of mechanical stresses applied to a previously annealed specimen was used as a reference value for the residual stresses. Different materials, different indentation tip geometry and different loading conditions were involved. The paper presents and discusses those results.

5856-60, Session 12

Superconductor ceramics behaviour analyses during service by speckle metrology

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One of the main technological problems of ceramics high temperature superconductors is inhomogeneous heating due to hot spot generation. Corrosion in the surface and the degradation of the sample in humid atmosphere are other relevant aspects to analyse during service of these materials.

This paper will show the feasibility of applying speckle techniques as a non-destructive evaluation of the performance of ceramic high temperature superconducting materials.

Firstly, Digital Speckle Pattern Interferometry has been applied to these materials during service, with the sample cooled to liquid nitrogen temperatures, to detect where a hot spot is generated. This is really very convenient in order to improve the development of technological applications with these materials.

Heat dissipation starts at some points of the material where the superconducting properties are the poorest ones. Due to the low thermal conductivity of the material, power dissipated at these points produces local heating and it can deteriorate the sample properties, eventually reaching the melting. Until now, the typical measurements based on usual electrical transport measurements give only information integrated along the length on the sample. Besides, in order to detect hot spot generation a high intensity passing through the material is required. DSPI measures deformations on the object due to dilatation associated to the heating produced by the energy dissipated at the material. As the sensitivity of the technique is better than 1 m, only a small amount of energy is required to produce a measurable deformation and the risk of damage to the sample disappears.

Surface corrosion due to humidity or the thermal process has been studied. As a global parameter could be enough and no a point by point technique is required, Speckle Photography, whose optical setup is more simple, has been selected.

5856-61, Session 12

Automatic detection of the natural frequencies using digital shearography

Y. Gan, W. Steinchen, Univ. Kassel (Germany)

Using the continuously refreshed reference frame in conjunction with the real-time subtraction allows time-averaged shearography to observe and to evaluate the vibrations in form of J02 -fringes in quasi real time. Since the fringe patterns are dependent on the vibration amplitudes, the resonance frequencies of the object can be detected due to the higher amplitudes in resonance. In this presentation a new technique is introduced to automatic detection of the natural frequencies without applying additional sensors by means of statistical method.This method is suitable for the automatic identification of flaws as well. An experimental investigation shows the detection of defects in a CFR material in this publication.

5856-62, Session 12

Experimental comparison of shearography and laser optical feedback imaging for crack detection in concrete structures.

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Early detection of defects on concrete structures, such as bridges or dams, is of a crucial importance since it makes maintenance tasks easier, hence minimizing the costs of repairs.

To be used in a real environment, compact and robust techniques are needed. In this work, we focus on optical, non-destructive methods that offer a global visualization of the structure, namely interferometry and laser optical feedback imaging (LOFI). Contrary to differential holography, which is very sensitive to environment fluctuation and needs precise adjustments, differential speckle interferometry, a.k.a. shearography, is a compact and more robust way to measure displacement gradients. LOFI is well suited to vibrometric measurements. The optical signal is modulated and amplified back in the cavity of the laser, hence providing robustness to environment fluctuation and enhanced detection performance, even with very attenuated signals. Image acquisition is performed using two rotating mirrors.

We report crack detection laboratory tests on a piece of armed concrete, stimulated by acoustic waves. Our results show a good correlation between the two techniques and the feasibility of detecting non-emerging (hence invisible to a human observer) cracks. The advantages of shearography are its compacity, resolution and rapidity (it is a direct full view technique), but, in this application, the information it provides is essentially qualitative. On the contrary, the LOFI technique measures the difference of amplitude vibration on each side of the defect. Moreover, its good sensitivity enables long-range measurement, but the image resolution and acquisition time depend on the tuning of the motor steps.

5856-63, Session 12

Interferometric optical tomography applied to dendritic crystal growth model scenes

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In the frame of science in microgravity, the investigation of dendritic growth in a solidification process has been chosen as a test case in order to determine the ultimate performance and the limits of interferometric optical tomography, a well dedicated optical diagnostic tool for transparent media.

Different static Model Scenes- made from glass fibers - have been manufactured and independently characterized in air by micro X-ray tomography. An optical tomograph based on a single arm Mach-Zehnder Interferometer, allowing to rotate the static objects, has been designed, built and calibrated. Sets with a different number of tomographic projections have been acquired as phase images from all Model Scenes. The optical projection data passed through a tomographic reconstruction process, the results of which were compared to the reconstructions gained from the micro X-ray measurements. Reconstructions for some of the object were successful allowing direct comparison with the reference data.

The paper will focus on the calibration of the tomograph, experimental results and the discussion on the potential of interferometric optical tomography. Further developments to go beyond the limits of interferometric tools are also proposed.

5856-71, Session 13

Characterisation of high-density particle distributions for optimisation of laser beam cladding processes using digital holography

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Laser beam cladding is an innovative surface treatment process which has several advantageous properties like a reduced material distortion compared to conventional techniques. In this technique the cladding material is fed as a powder through the laser beam to the melt pool. For an optimisation of this process with respect to treatment time and efficiency a

characterisation of the powder size, distribution and velocity is crucial.

Holographic particle image velocimetry is a powerful tool for characterisation of particle distributions with respect to size, 3D-position and velocity. Due to the holographic recording principle 3D-information can be evaluated from just on hologram. Its major drawback, the time-consuming development and repositioning of the hologram plates, can be avoided using the well-known technique of digital holography. In this case the hologram is recorded by a CCD-camera and reconstructed numerically.

Common digital holographic particle measurements are performed using an inline configuration in order to minimise the experimental effort. In this case the measurements are limited to low-density particle fields due to increased noise generated by an overlap of real and virtual image in the reconstruction process.

In this paper the application of off-axis digital holographic particle velocimetry to the characterisation of powder distributions in a laser beam cladding process is presented. Besides the experimental realisation special emphasis is given to the numerical reconstruction of the 3D-position and velocity of the particles. In extensive tests the suitability of the proposed technique is demonstrated. In the powder measurements up to 300 particles are detected with diameters of about 100μm and characterised with respect to position in a volume of about 1cm3 from just one hologram. In addition the speed of the particles is determined by double pulse measurements.

5856-72, Session 13

Laval nozzle flow characterization by Fourier-transform Mach-Zehnder interferometry

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The role of the assist gas blown by a nozzle during the laser cutting process of ceramics is very important as a complex flow field is created by the interaction with the material. Flow visualization provides valuable information related with the properties and characteristics of the process in order to clear up misconceptions and as a first step towards the nozzle optimization. Optical methods as shadowgraph, Schlieren, holographic interferometry, particle image velocimetry or interferometry are suitable techniques for this task as well-known non-intrusive methods employed for analysing fast transient phenomena. In this work a Laval nozzle is characterized by analyzing the shock wave pattern provided by the interaction of the gas flow against a transparent model of the processed material in a Mach-Zehnder interferometer. The optical phase is extracted from the obtained high-frequency fringe pattern by the Fourier Transform Method. Disturbing effects are cancelled by sequential subtraction of two phase maps obtained with and without gas flow, respectively. The shock wave pattern is analyzed for different geometrical configurations and operating pressures.

5856-73, Session 13

Methods based on one component laser Doppler anemometer and hot film anemometer for three-dimensional turbulent measurements

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Zeris A., Prinos P.,Koutitas Ch.

ABSTRACT

In the present article, an experimental study is conducted for the investigation of the turbulent flow field in the three directions at simultaneously with the aid of one component Laser Doppler Anemometer and the traditional x Hot Film sensors. The application of the present technique is conducted on fully developed uniform open channel flow and on flow with suction from the bed.

Suction from wall has practical and theoretical interest in a variety of engineering applications with significant effect on mass, momentum and sediment transport phenomena. The impose of suction results in an unknown direction of the main velocity at least inside the suction region. Measurements were conducted in an open channel flow, with total length 12m with hydraulically smooth bed. Suction rates from 0.01 to 0.08 were imposed from a perforated plate with length of 0.035m. Re numbers from 10000 to 60000 were studied. Velocity measurements were made with Laser Doppler Anemometer and Hot film Anemometer. A one component LDA with forward scatter (Dantec optics), 15mW He-Ne with frequency shifter was used and the photomultiplier signal was processed with tracker before the digitization process. Variation of flow depth, alteration of the law of the wall of the mean velocity profile, turbulent intensity distributions , skeweness and kirtosis distributions, Re stresses and power spectral densities have been analysed and are well documented for the streamwise direction.

The aim of the present study with the low cost one component LDA, is the development and estimation of methods for the simultaneously acquisition of the whole turbulent flow field (u,v,w) and the estimation of main velocity in situation with unknown direction of the two dimensional flow field, such as in the case above the suction region and secondly the contribution of LDA on hot film calibration.

The one component Laser Doppler Anemometer is used in collaboration with the x hot film sensors in the horizontal and in vertical direction for the estimation of the calibration curve of the hot film sensors for the required range of Re numbers that will be used in the set of measurements of a flow depth.

In the next step, with the appropriate orientation of LDA and taking into account transformation coming from the theory of zero correlation between direction and velocity in stationary flows, the three components of velocity of the flow field are extracted. All Re stresses are calculated, with the advantage the error reduction relative to methods from independent measurements. Finally, the full database leads to investigation such as coherent structures of streamwise direction based on thresholding criteria (VITA,wavelets) from the rest directions and to spectral and co spectral analysis of the extracted turbulent quantities.

5856-74, Session 13

Measurements of material refractive index with a circular heterodyne interferometer

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A circular heterodyne interferometer consists of a circular heterodyne light source, a tested sample located on a rotational stage, an analyzer, a photo detector, and a phase meter. A light beam coming from the heterodyne light source in incident on the tested sample and reflected. The reflected light passes through an analyzer and enters a photo detector. If the transmission axis of the analyzer is located at 45 deg. with respect to the horizontal axis, then two orthogonal polarized components are extracted to interfere. The interference signal detected by the photo detector is sent to a phase meter to compare with the reference signal coming from the driver of the circular heterodyne light source, the phase difference between two orthogonal polarized components can be measured accurately. This measured data is substituted into the special equation derived from Fresnel equations, the refractive index can be estimated. In order to show its validity, some glass plates and a uniaxial crystal are tested. Because its common-path configuration and heterodyne ineterferometric phase measurement, it has both the advantages of the common-path interferometer and the heterodyne interferometer.

5856-120, Session 13

On-line, non-contact measuring of synchronizer hubs

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Accurate measurements of complex sintered pieces is a slow process, requiring costly installations and equipment, and trained personnel. In on-line production, this leads to quality control and process feedback solutions where only a small set of pieces are fully inspected (with a high delay between the time they were produced and the time they are inspected). Also most of the production is tested by go/no go caliper gauges than can only ensure that the piece is inside the tolerance levels for some of the dimensions.

In the industry of sintered automobile synchronizer hubs, as in many others, a fast on-line measurement system for the 100% of the production is a very important tool for production and quality control, enabling among others: extended quality control of the 100% of the production, lower start-up times, improved knowledge of the process and influence of its parameters and database management of the information.

The rapid evolution in the concepts of verification and measuring methods as well as the increasing demand for tighter tolerances and detection of shape defects have resulted in a collaboration between Sinterstahl Asturias, Korvus Tecnologia y Desarrollo and the University of Oviedo for the develop of a new measuring system with these new requirements in mind.

The system uses a conoscopic holography-based measurement device, from Optimet (Optical Metrology Ltd.) called “conoprobe”, to obtain the external contours of the synchroniser hubs. This data are used to characterise particular features such as shape defects or tooth profile in synchronizer hubs.

The introduction of the paper outlines the mechanical system where two independent structures are used, the load/unload cell and the measurement column. The load/unload systems are used to feed pieces into the measurement column witch is able to work with 3 hubs at the same time: when the first one is loading the second one is measuring and a third one is unloading. This performs measurements at a high operation speed of 1 hub each 7 seconds with measurements at 3 heights. If we want to measure more heights the system needs 1 second more per additional height. In this part of the paper a brief introduction of the conoscopic

holography is also presented.

Along the paper we deeply focus on the effects of the errors (mechanical error of the vertical translation, holding errors, eccentricities on rotation motion, etc) in the resolution and the accuracy of the measurement and the solutions we adopted to solve or to minimise them. We also show the need of a recalibration process to compensate the thermal dilation of hubs or/and the whole system and how the encoder precision of the rotation motion is influencing the quality of the measurements.

To validate the developed system several Repeatability and Reproducibility (R&R) tests were done using the ISO 5725-2:1994 standard (Basic method for the determination of repeatability and reproducibility of a standard measurement method). From 10 hubs from different populations made in different production series and measured nine times each one at different moments a R&R of 0.009 mm with a maximum fluctuation of 0.004 mm is obtained. These tests prove the behaviour of the system, built with standard, no high accuracy, commercial elements, and the performance of the described methods.

5856-64, Session 14

Assessment of technology and (thermo) mechanical behaviour of MEMS devices by interference microscopy

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No abstract available

5856-65, Session 14

Laser acoustic characterization of Ta and TaN diffusion barriers beneath Cu layers

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The replacement of aluminum by copper as interconnect metal in computer chips was and still is driven by the necessity to enhance the current density thus enabling higher packaging densities, a fact that correlates directly with faster, smaller, and less energy consuming devices.

The usage of copper, however, leads to new technological challenges which are caused by its mechanical properties on one hand side and by is tendency to migrate into dielectric and/or semiconducting layers on the other hand side. To prevent such diffusion processes, very thin layers consisting of tantalum and tantalum nitride or titanium and titanium nitride are deposited.

A non-contact, non-destructive, short-pulse-laser-acoustic method is used to determine the mechanical properties of the barrier layers and of the copper layer. Mechanical waves are excited and detected thermoelastically using laser pulses of 70 fs duration. For metals this leads to wavelengths of 10 to 20 nm and the corresponding frequencies amount to 0.3 to 0.6 THz. Thin film measurements of buried diffusion layers are provided and compared with Scanning Electron Microscopy measurements (SEM) and Rutherford Backscattering Spectroscopy measurements (RBS).

Limits of the presented method are discussed and future directions of the on-going research project are presented.

5856-66, Session 14

Thin film measurements by noise in dynamic force microscopy

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The micromechanical cantilevers has become a powerful tool for the study of forces at nanoscale and serves as the heart of the Atomic Force Microscope (AFM) and of all the Scanning Force Microscopes design on this basic idea. These micromechanical cantilevers are forced to not negligible thermomechanical oscillations at room temperature induced by the thermal noise, which is a Brownian motion. These oscillations impose a fundamental limit to the accuracy of force detection setups in AFM.

However these thermomechanical oscillations can be analysed in order to obtain information about the tip-sample interaction. Several applications have been presented in the last years demonstrating the potential use of the thermomechanical noise. In all these publications the authors describe the evolution of the resonant frequency of the microcantilevers through the spectral power density in the case of non-contact behaviour or by studying liquids or gas samples, with the standard optical lever technique. They have observed that it is impossible to detect the resonant frequency by this way in the case of contact with hard samples.

Here we report on the investigation of mechanical sample properties by analysis of the thermomechanical noise of the first symmetric eigenmodes of a rectangular microcantilever. The presented work is the first study demonstrating the possible detection of the first flexural vibration modes of the microcantilever in contact with hard samples, by optical probing of the thermomechanical noise. In contrast with the previous authors we use a high sensitivity heterodyne interferometer (resolution of this laser probe is about 5.10-3 pm/ÖHz), which allows probing of the absolute amplitude of the Brownian motion of the microcantilever.

By Analysing the spectral density of the thermomechanical fluctuations attributed to the first symmetric flexural vibrational modes of the surface-coupled cantilever, the longitudinal stiffness of the tested sample can be obtained. Experimental results will be presented concerning the characterization of thin films.

5856-67, Session 14

Enhancement of image contrast by fluorescence in microtechnology

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New developments in production technology increasingly focus on hybrid microsystems. Especially for systems with movable components the process step of assembly is mandatory. In general the accuracy of positioning of the parts has to be better than 1μm. This makes specialized and automated production equipment necessary which can lead to a conflict with the aim of flexibility of the range of products. Design for manufacturing is a well known remedy. Assembly aids are common practice today. These features of the workpieces bear no functionality for the end product but considerably ease certain process steps. By standardization of assembly aids generalized production equipment free from product-specific features could be developed.

In our paper we demonstrate the photogrammetric determination of the positions of workpieces without reference to their exterior shape, using circular fiducial marks of 150μm diameter. The surface properties of the workpieces, however, still have an influence on image formation. As an example the marks may be hidden by local specular reflections. A solution to this problem is to add an exclusive optical property to the fiducial marks to get an image with high contrast against the surface of the workpiece. In biology and medicine samples are stained with fluorescing dyes to enhance the contrast in optical microscopy. In fluorochromes light of a characteristic wavelength is emitted after the absorption of light with a shorter wavelength.

In our experiments we added a fluorochrome to a common photoresist and coated the surface of the workpiece with a thin layer thereof. Using photolithography as a patterning technique we generated fiducial marks with structures down to 25μm. These marks can be identified by their characteristic emission wavelength under short-wavelength illumination. Small-bandwidth optical filters are used to suppress all the unwanted parts of the image. Only the fiducial marks remain and processing these images is straightforward.

The generation of fluorescing patterns by photolithography opens new possibilities for testing and process control in many fields of microtechnology.

5856-69, Session 14

Point-diffraction fiber interferometer for vibration desensitization

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We present a new type of point-diffraction interferometer specially designed for industrial use with high immunity to external vibration encountered in the course of measurement process. The interferometer uses thermally-expanded fibers instead of conventional pinholes as the point-diffraction source to obtain a high quality reference wave with an additional advantage of relatively easy alignment of the interferometric optical setup. Vibration desensitization is realized through a common-path configuration that allows the influence of vibration to identically affect both the reference wave and the measurement wave and be subsequently cancelled out during the interference of the two waves. A new type of spatial phase shifter is also added to capture four phase-shifted interferograms simultaneously without time delay to avoid vibration effect. Performance of the proposed interferometer is verified through a series of defect inspection made in real time on the production line of glass substrate panels used for fabrication of liquid crystal displays.

5856-70, Session 14

Digital holography microscopy (DHM): fast and robust systems for industrial inspection with interferometer resolution

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With the recent technological advances, there is an increasing need for measurement systems providing interferometer resolution for inspection of full wafers of micro lenses, biochips, or micro-elements, and of large quantities of individual samples. For such applications, high measurement rates, robustness, ease of use, and non-contact systems are required. Off-

axis Digital Holography Microscopy (DHM) meets these requirements.

Light interaction with a sample modifies both intensity and phase of the illuminating wave. Any available supports for image recording are sensitive only to intensity. Denis Gabor invented in 1948 a way to encode the phase as an intensity variation: the “hologram”. Digital Holographic Microscopy (DHM) implements digitally this powerful hologram. With the present power of computers and the developments of digital cameras, holograms can be numerically interpreted within a tenth of second to provide simultaneously: (1) the phase information, which reveals object surface with vertical resolution at the nanometer scale along the optical axis, and (2) intensity images, as obtained by conventional optical microscope. Both images are defined with a diffraction limited resolution in the transverse (oxy) plane and are available in real time (more than 10 frames per second).

The strength of DHM lies in particular on the use of the so-called off-axis configuration (Fig. 1), which enables to capture the whole information by a single image acquisition, that is to say typically a few ten of microseconds using a standard camera and down to two microseconds with fast cameras up to 100’000 frames per second. These extremely short acquisition times make DHM systems insensitive to vibrations. These instruments can operate without vibration insulation means, making them a cost effective solution for an implementation on production lines.

The presentation will include numerous application examples, such as shape and surface characterization of high aspect ratio micro-optics, MEMS and MOEMS, surface nano-structures, and thin films.

The development of the technology has been supported by Swiss government through CTI grants TopNano 21 #6101.3 and NanoMicro #6606.2 and #7152.1.

5856-121, Session 14

Enhancement of high-resolution electronic autocollimators by application of phase grating technology

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In high resolution electronic autocollimators which make use of CCD-arrays for the photoelectric detection of the reflected reticle line image, the sub-pixel interpolation can e.g. be improved by use of multiple slit arrangements. The newest developed instruments reach an angular resolution of 0,001 arc sec in a range of +- 1500 arc sec. The calibration of such autocollimators can be made with an uncertainty down to 0,01 arc sec (k = 2).

These values only can be assumed under well defined working conditions. It is of great interest for ultra-precision angular adjustment and quality control to estimate limiting factors and to specify a suitable parameter range. In addition to that it is a logical step forward to investigate opportunities to widen the suitable parameter range.

An evaluation of the angular range within an autocollimator can be used with reasonable accuracy was made. The evaluation is based on a simulation of the optical system. The resulting point spread function and the complex function of transmission of the reticle gives the image properties of the autocollimator. The electronic image processing - e.g. based on an edge detection algorithm - may provide a different angle measurement value at less accuracy if the image of the multiple slit arrangement is spread out. Thus the accuracy of autocollimators may decrease if the working conditions are not within a suitable range. Limiting parameters are - among others - the working distance, the numerical aperture, the z-position of aperture stops and the decentration perpendicular to the optical axis, the x- and y-position of aperture stops.

The simulations are compared with measurements done with a reduced numerical aperture and an increased distance between the autocollimator and the surface under test.

To enlarge the range of the parameters for high accuracy autocollimator applications, image enhancement techniques can be used. That implies to manipulate the complex function of transmission of the multiple slit arrangement in a way the spread out of the image can be reduced. This can be done by the introduction of an alternating phase function.

The simulations made had shown that a high accuracy can be obtained even if small apertures or small surfaces under test are used. In this case the uncertainty caused by the spread out of the image of the reticle can be reduced by a factor similar to 1/3. Furthermore the dependence of the accuracy of the measurement on the distance of the surface under test is reduced. Thus a significant enhancement of the performance of high resolution electronic autocollimators can be obtained.

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5857-02, Session 1

Laser techniques in conservation in Europe

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The state of the art of laser techniques employed in conservation of cultural heritage is continuously growing in Europe. Many research projects organised at the European level have contributed to this achievement, being complementary to the development carried out at national level. The COST Action G7 is playing its unique role since the year 2000 promoting the experimentation, comparing the experiences and disseminating best practices. This role has been particularly effective for monitoring of the results of many short-term research projects completed along the G7 Action lifetime. After that several laser cleaning techniques have been followed and evaluated in their results, it appears now clear an evolution of the systems, a specialization of the cleaning task, the achievement of side-effect free procedures. The validation of these advanced cleaning techniques has been extensive and diffused in many European countries, especially for stone and metals. Laser-based diagnostics have also specialised their tasks toward material analysis, defects detection and multidimensional documentation. Laser and optical methods successfully monitor deterioration effects. In many European countries interdisciplinary networks are managing the experimentation of these techniques giving them a sound scientific approach, but also a technology transfer to end-users. So doing the appreciation for these techniques is growing in all the conservation institutions involved at national level, disseminating a positive evaluation about the benefits provided by laser in conservation.

Nowadays laser cleaning is considered the most precise method available for the restoration intervention, in order to remove in a controlled way the degraded layers. Several laser systems became products for the activity of professional restorers and their increasing sales demonstrate a growing utilisation throughout all Europe.

5857-03, Session 1

Non-destructive investigation for the assessment of cleaning interventions on pentelic marble surfaces

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In this work, a non-destructive investigation was performed on Pentelic marble surfaces of the Historic Building of National Archaeological Museum in Athens. The investigated Pentelic marble surfaces disclosed representative decay patterns that usually develop in polluted urban atmosphere such as the Athens' centre. Therefore, the applied non-destructive investigation aimed to collate as much as possible evidence about the physico-chemical and aesthetical characteristics of the examined surfaces before and after the pilot cleaning treatments, in an attempt to configure a self-reliant and effective non-destructive approach for the planning of cleaning interventions and their assessment. The applied non-destructive investigation included fibre optic microscopy (FOM), infrared thermography (IR-Thermo), colourimetry and laser profilometry (LP). In particular, FOM was used for surface morphology and texture assessment. That is identification and classification of decay patterns before cleaning, whilst after cleaning, alterations of the surface morphology, especially concerning the decay patterns removal, were attained. Moreover, supplementary information concerning the mineralogical study was obtained. IR-Thermo was employed in order to investigate the architectural surfaces for the thermal contrast and the temperature distribution width variations before & after the pilot cleaning interventions. Laser profilometry was employed for the samples surface topography assessment which was characterised by the Rq roughness value. Colourimetry was applied on the examined surfaces, before and after the pilot cleaning treatments, in order to estimate colour parameters modification. The results were encouraging enough to indicate that a non-destructive approach, as far as assessment of cleaning conservation interventions on Pentelic marble are concerned, can be proposed.

5857-04, Session 1

Cleaning and characterisation of objects of cultural value by laser ablation

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Surface ablation with nanosecond lasers pulses were applied to the preservation, cleaning and identification of the composition of objects of cultural value.

On one hand, treatments of fabrics, coins, glass bottells and other urban archeological objects is shown, as well as applications to the preservation of covers and fronts of books and old manuscripts made in rag paper. Damage fluence thresholds of 17 different XIXth century types of papers, made by processing textiles, were determined. Quality of the laser cleaning methods were compared with conventional ones, by using digital image processing.

On the other hand, we discuss the advantages, with respect to conventional methods, of using the analysis of the plasma generated as a result of laser ablation (LIBS- laser Induced Breakdown Spectroscopy-) for the determination of the elementary composition of unique pieces in anthropology and archaeology. In particular, we show applications to the identification of trace elements in Hominides teeths, concerning the analysis of eating habits; to the determination of the composition of objects of different materials belonging to different pre-Columbian cultures (axes, bracelets, ceramics, etc.) and to the characterization of surface dirt and contaminants deposited on this objects.

5857-05, Session 1

Optical and thermal confinement in laser cleaning of artworks

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No abstract available

5857-06, Session 1

Laser dusting of delicate objects

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Since the inception of the laser-divestment process, emphasis has focused on the treatment of reasonably durable materials. Marble, limestone, sandstone, and bronze have been foremost among these. In most situations the objective of laser divestment is the removal of superficial corrosion or chemical-decomposition accretions. To a lesser extent laser ablation is also used to treat diverse surface defects of a spectrum of other historic and artistic substrates such as paper, vellum, ivory, paint, or plaster. Although materials of this sort are not particularly strong, their optical, thermodynamical, and mechanical properties are sufficiently propitious to enable successful laser treatment (with the exercise of precise control). There is another, quite different, cleaning problem encountered in the maintenance of museum collections. This is often referred to as "dusting" (in contrast to "divestment" or "conservation"). Vacuuming, wiping, blowing, and feather dusting are used most often to improve the cosmetic appearance of museum objects after dust and aerosols have accumulated on exposed surfaces. However, many collections include extremely friable pieces with feathers, fur, hair, plant fibers, or mummified skin. Conventional dusting is sometimes impossible in such instances. We present experimental results and analyses, showing that safe laser dusting is possible on the above materials. Evidence suggests that at very low fluxes, laser-induced acoustic and electrostatic forces are responsible for the ejection of debris. The practical viability of laser dusting was demonstrated by employing it on two very large sand sculptures by San Diego artist C.R. Faust. In contrast, all conventional cleaning techniques damaged the surface by dislodging individual sand grains of the artworks.

5857-30, Poster Session

Hyperspectral imaging for the recovery of erased and overwritten scripts in old historic manuscripts

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Palimpsests -twice written manuscripts- are of great interest since they may contain important hidden text underneath the visible one. Hyperspectral imaging may aid the expert to read the old script by separating the information. We present a Hyperspectral imager, developed at Forth-Photonics, capable of acquiring 34 calibrated spectral bands in the range of 360-1150nm (extended to 1550nm when coupled with a photocathode tube). The system enables the acquisition and display of narrow-band images and a fully resolved diffuse reflectance and/or fluorescence spectrum at each individual pixel. Spectral information allows for non-destructive analysis and identification of inks and paper, while imaging at narrow spectral bands enables the optical contrast enhancement between scripts and background by selecting spectral bands corresponding to their maximum spectral differences. We have developed and implement in the Hyper spectral system, image processing algorithms to further visually enhance the hidden text against the parchment and to suppress the upper script in order to aid the expert in reading the

underlying text. The developed software exploits the whole range of spectral bands (spectral cube) and selects the high contrasted ones using PCA (Principal Component Analysis). On the selected images, morphological and anisotropic diffusion operators are applied to further enhance the visualization and separation of scripts thus enabling the recovery of overwritten or partially erased scripts. Hyperspectral imaging combined with powerful image processing tools has the potential to become an indispensable tool for the analysis of old manuscripts.

5857-34, Poster Session

Novel application of optical coherence tomography for painting diagnostics

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In the last few years a variety of non-destructive techniques have entered the field of painting diagnostics and conservation, and most of them are routinely applied to study the painting status as well as to monitor the various phases of the restoration process. Among them optical techniques are by now widely diffused and extremely well received because of their effectiveness and safety.

A painting can be described as an overlapping multi-layer structure: from back end to surface, a wooden or canvas support, a ground layer, one or more painted layers and a protective varnish film are typically present. This latter, generally spread on the painted layer either to protect it or to make it brilliant, is subjected to yellowing and darkening depending on ultraviolet radiation exposure, dust deposition and over-painted varnish films. The original appearance of the painting results, thus, in an altered polychromy, requiring partial or complete removal of varnish, without damaging the underlying layer. For that reason one of the most important and often controversial stages of painting restoration is the surface cleaning process. Up to now it has been carried out without any tool to measure the actual varnish thickness (typically of the order of a hundred microns) but microscope observation of micro-detach.

In this work we present a novel application of Optical Coherence Tomography (OCT), a well-established technique for biomedical applications, for non-destructive measuring of the varnish film thickness of ancient paintings. OCT images of a fragment of a nineteen-century oil painting are also shown.

5857-35, Poster Session

Profilometry of medieval Irish stone monuments

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National monuments are at ever-increasing risk of severe and permanent damage. The 3D laser scanning of stone monuments brings a new dimension in the field of cultural heritage by providing means of preserving, visualizing, accessing and analysing some of its most invaluable artefacts. In this article, we present the results obtained with our project “Profilometry of Medieval Irish Stone Monuments” hosted at the Centre for the Study of Human Settlement and Historical Change, NUI Galway. This project aims to create a virtual archive of selected incised stones from 3D scans taken in the field. The raw scans are processed into watertight 3D models and new processing techniques have been developed to enhance the surface features of the stones. Also, textured 3D models of the artefacts have been made available online for the benefit of both the historian community and the broader public. This article focuses on the analysis we performed on the shaft of the east cross at Toureen Peacaun, Co Tipperary, which shows the longest inscription in Ireland with geometrical capitals.

5857-36, Poster Session

Application of 3D laser scanning technology in historical building preservation: a case study of a Chinese temple

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Chinese temple architecture is characterized by its intricate designs and decorations applied to eaves, roofs, balustrades, pillars, gateways, and interior ceilings. The high-leveled architecture techniques have complicated the treatments of conserving and restoring heritage inherited styles and features from its hundred- or thousand-year history. To build up a non-destructive measurement method that functions effectively and efficiently in dealing with the preservation of cultural and historical heritage complex is a task of vital importance for it presents not only domestic concern but also common interest of the world community.

This study applies 3D laser scanning technology to develop a high-precision measuring system for digital survey of historical building. It outperformed other methods in obtaining abundant high-precision measuring points and computing data instantly. In this study, the Pei-tien Temple, a Chinese Taoism temple in southern Taiwan famous for its highly intricate architecture and more than 300-year history, was adopted as the target to prove the high accuracy and efficiency of this system. By using French made MENSI GS-100 Laser Scanner, numerous measuring points were precisely plotted to present the plane map, vertical map and 3D digital map of the property. Accuracies of 0.01-0.1 mm in the digitized data have consistently been achieved for the historical heritage measurement.

5857-38, Poster Session

Probabilistic image-based characterization of manuscript inks

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Inks found in Byzantine manuscripts are semi-transparent pigments and their examination and analysis provide an invaluable source of information on the authenticity and dating of manuscripts and the number of authors involved. Manuscript inks are made through the combination of inorganic and organic pigments such as metals, salts and vegetable materials. Existing methods used for the examination of pigments can be applied in the analysis of manuscript inks, however, most are based on destructive testing techniques that require the physicochemical sampling of data. Such methods cannot be used widely because of the historical value of the manuscripts.

In our work we use image-based techniques to complement the reflectographical methods of analysis by computing models and interpreting the visual properties of the inks in the visible and infrared areas of the spectrum, therefore providing an in situ and portable quantitative method for the discrimination of the types of inks used in old manuscripts. Our work is based on the representation of the manuscript inks in the infrared and visible areas of the spectrum using a mixture of Gaussian functions and the analysis of co-occurrence matrices that encapsulate image variations in the inks due to the scripting process.

During our experiments we created images to reflect the scripting conditions found in manuscripts and encapsulate: a) the varying thickness of the inks during scripting; b) the varying scripting formed due to the different means of writing used; and c) the writing characteristics of different authors. The images used during our experiments can be separated to those of known chemical composition and include both model and test images and those of unknown chemical composition that were taken directly from Byzantine manuscripts where X-Ray Fluorescence spectrography (XRF) was used to verify the results derived by the image-based process. The following observations are made: a)In model images most of inks are capable of classification with over 80% success rate when screening results are taken into account. The only exception is the carbon ink, which presents the lowest successful results. However, carbon ink can be screened in the infrared area (over 60% success rate) and the visible area (over 80% success rate); b)In test images mixed, typeC, typeB and irongall inks can be identified in the infrared area with a certainty of 75% to 100%. TypeA ink can be identified or screened in both the infrared and the visible areas with a certainty reaching 60% in the visible area of the spectrum. Carbon ink can be identified in the visible area; c)The characteristics of three out of the four unknown inks found in Byzantine manuscripts were determined.

5857-39, Poster Session

Proposal for an analytical sequence aimed at establishing sutcco’s composition and technique used. Study of samples collected in southern Switzerland

G. Cavallo, Scuola Univ. Professionale della Svizzera Italiana (Switzerland); M. Moresi, Univ. degli Studi di Bari (Italy)

The paper presents the results of experiments obtained using different analytical techniques (optical and electronic microscopy, infrared spectroscopy, powder X-ray diffraction, X-ray fluorescence, microanalysis) performed on stucco samples from churches and historical buildings in Canton Ticino and Canton Grigioni (Southern Switzerland).

The research is principally oriented towards establishing the better analytical sequence for an efficacious characterization of materials and techniques used in making stuccos, in order to satisfy restoration requests.

Plastic decorations (stuccoes of XVII and XVIII century) and vertical surfaces imitating marble (XIX century) were studied.

The experimental data showed the same bottom layer for all the samples (common lime and silicate aggregates coming from the alluvial deposits of the Ticino river); different categories of stucco are distinguishable

observing the finishing layer characteristics (marble stucco known as marmorino, shiny stuccoes and so-called stucco).

Petrographic examinations and spectroscopic infrared analyses represent a suitable survey sequence, working on samples of millimetric size (low invasivity and high representativity) and considering that it is an usual necessity to divide mechanically the different parts of the same material, as for example bottom layer and finishing one, to detect the presence of organics compounds in each layer. More significant results should be obtained employing electron microscope and microanalysis performed by SEM, using the same thin polished section of optical examinations.

Mineralogical and chemical analyses performed by X-ray diffraction and X-ray fluorescence require a greater sample availability but in this way it is possible to obtain more complete and representative information specifying compounds bound to alteration processes and/or to previous restoration interventions.

5857-40, Poster Session

Sulphur selective ablation by UV laser

V. Nassisi, F. Belloni, G. Buccolieri, G. Caretto, A. Castellano, A. Lorusso, Univ. degli Studi di Lecce (Italy)

In this work we report the preliminary experimental results on the selective ablation of S in ancient stones. Its concentration was reduced after laser action. For this goal an excimer laser operating at a wavelength of 308 nm and time duration of 20 ns was used. In order to estimate the sulphur concentration before and after laser cleaning, a portable apparatus for energy-dispersive X-ray fluorescence (EDXRF) was utilised. The samples processed had got an initial sulphur concentration of 2.8% w/w. After laser application its value decreased up to 1.2% w/w. This result was reached by a laser energy density of about 1 J/cm2 applied for 30 s at a laser repetition rate of 1 Hz. After a few laser shots, the initial black area of the no-treated stones became white due to the laser ablation processing.

5857-42, Poster Session

A fuzzy logic system for Raman spectrum identification

M. Castanys, Univ. Politècnica de Catalunya (Spain); R. Pérez-Pueyo, UPC (Spain); M. J. Soneira, Univ. Politècnica de Catalunya (Spain)

Raman Spectroscopy is an analytical technique which has experienced a great increase in interest because of the wide range of analytical applications that have appeared. Between all the existing applications, the one which has been growing in importance in recent decades is the investigation of artwork and artistic materials. This analytical technique is based on the optical effect known as the Raman Effect.When monochromatic light encounters matter, most of the scattered light has the same wavelength as the incident light. However, a small fraction of the scattered light, is shifted in a different wavelength by the molecular vibrations and rotations of the molecules in the sample. The spectrum of this wavelength_shifted light is called Raman Spectrum,and consists of scattered intensity plotted versus energy, and contains many sharp bands characteristics of the specific molecules in the sample. Due to this, a single Raman spectrum can provide a large amount information about a sample, being like its fingerprint and allowing its identification without ambiguity.

In this communication, a fuzzy logic system to recognize Raman Spectra of artistic pigments is presented. The identification is based on the comparison between the unknown spectrum coming from the analysed sample, and the spectrum collected in a data base called pattern spectrum. Frequently the comparison is made by the spectrospist by visual inspection, but this is a slow, imprecise and non automatic process which introduces a component of subjectivity. In order to mitigate this problematic, a system based on the fuzzy logic technique to compare and identify in an automatic way Raman Spectrum is presented. The methodology consists on implementing the comparison with a mathematical operator, the Correlation, and then, according to its results, decide if the two spectrum represent or not the same pigment.

In Raman Spectroscopy the spectra are usually and inevitably contamined by noise inherent in their own acquisition that introduces ambiguity into the correlation values. Fuzzy Logic provides a simple way to draw conclusions from vague, ambiguous or imprecise data. The fuzzy Raman Spectroscopy identification system is based on the following statement: when the correlation between the unidentified and the pattern is enough high, the analysed pigment is recognized as the pigment which corresponds to this pattern.

The membership functions, which characterize the fuzzy sets at the input (Correlation) and output (Identified/ Not_Identified) of the system, and the inference mechanism suitable for the problem, are chosen.

5857-43, Poster Session

Optical characterization of fresh and thermally aged varnish films by spectroscopic ellipsometry for application in Byzantine icon conservation

K. S. Polikreti, C. Christofidis, Univ. of Cyprus (Cyprus)

The specific aim of this paper is to assess the change in the optical characteristics of varnish layers due to heating, by spectroscopic ellipsometry. Spectroscopic ellipsometry has recently been proved useful in the optical characterisation of varnish layers.

Samples of fresh natural and synthetic varnishes applied on glass were analysed: dammar, mastic and egg white (prepared according to traditional recipes), mecca balsam and Paraloid B72. The refractive indexes of fresh and heated samples of known thickness were described by the Cauchy law on n and k: n(λ) = A + B/λ2 + C/λ4, k(λ) = D/λ + Ε/λ3 + F/λ5. The ellipsometric data were fitted to a model, which includes a mixed varnish-air layer. The optical properties of this layer were calculated by the Bruggeman effective medium approximation. The results give the refractive indexes of fresh varnish in the spectral range of 300-850nm and illustrate the rate and degree of optical alteration caused by heating.

The measurements were repeated for samples on carbon black acrylic paint. In this case, another mixed layer (paint-varnish) was added to the model. The results were very close to those obtained in the case of the glass substrate. This step is very important because our future work aims to in-situ, non-destructive measurements on original Byzantine icons.

5857-44, Poster Session

Integrated optical and nuclear microprobe for material analysis

L. Calcagnile, G. Gianfrate, G. Quarta, L. Maruccio, D. Muscogiuri, Univ. degli Studi di Lecce (Italy)

We present the general features of the new nuclear microprobe beamline developed at the CEDAD - CEntro di DAtazione e Diagnostica, the new established facility of the University of Lecce, Italy. The Center is devoted to the development and application of nuclear techniques to radiocarbon dating and ion beam analysis for material sciences, environmental and biomedical studies. The accelerator is equipped with three experimental lines for accelerator mass spectrometry radiocarbon dating, in vacuum and in air ion beam analysis. The new beam line is connected to the 30° exit port of the high energy switching magnet of a 3 MV TandetronTM-type linear accelerator manufactured by High Voltage Engineering. The nuclear microprobe, supplied by Oxford Microbeam Ltd (UK), delivers in vacuum a proton beam with a final spot of 1-3 μm. The expermental chamber has been designed such that the probe ion beam can be extracted through an exit window to perform the ion beam analysis in air and, together with this charged particle beam, a tunable laser beam can be focused on the target surface. The system is equipped with a luminescence detection and analysis system. The objective was to create a new powerful tool for material analysis that employs both nuclear and optical beams on the same sample; in this way the phenomena induced by a beam can be monitored by the other one.

It will be possible to perform, at the same time, in vacuum and in air, ion beam analysis and optical characterisation by laser and ion induced luminescence of materials.

The preliminary application is on Cultural Heritage Materials, as laser ablation monitoring of ancient metallic artefacts.

5857-45, Poster Session

Quantitative approach based on IR spectroscopy for a “quality control” of bone samples for AMS radiocarbon dating

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Sample preparation is a critical step for AMS radiocarbon dating in terms of accuracy of the results. Bone samples suffer in a particular way of contamination and deterioration, depending on their conservation state and previous restoring and consolidation processes. In the Sample Preparation Laboratory of the CEDAD (Centre for Dating and Diagnostics) of the University of Lecce we are studying a quality control protocol for the collagen extracted from samples based on FTIR spectroscopy (Spotlight(tm), Perkin Elmer). By this technique it should be possible to distinguish protein and signals of collagen from organic contaminants and consolidation compounds and estimate their relative quantities. We carried out a preliminary study on modern fresh collagen, in order to optimize both FTIR measuring protocol and the minimum sample quantity: it is important to reduce to the minimum the amount of ancient sample. We are also carrying out the analysis of the most common consolidation compounds. We carried also out some comparison measurements on collagen from ancient samples, in order to evaluate the conservation state of the samples.

5857-07, Session 2

NRC's 3D imaging technology for museum and heritage applications

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In 1981, the National Research Council of Canada (NRC) commenced research on the development of 3D imaging technology. In 1984, several Canadian museums and art galleries including the Canadian Museum of Civilization and the National Gallery of Canada started collaborating with NRC on the development of the museum and heritage applications of the technology. Subsequently, international heritage institutions in France, the UK, Italy, USA, Israel and China also became interested and participated in applications development projects. As a result, the museum and heritage sector became the main driving force for the development of NRC's 3D imaging technology.

This work has resulted in the development of a complete suite of 3D imaging technology tools and expertise which can be used not only for wide range of museum and heritage recording applications but also for industrial, medical, space and forensic applications. The technology suite includes the development of high-resolution laser scanner systems as well as software for the preparation of accurate 3D models and for the display, analysis and comparison of 3D data. Tools have also been developed for cost effective interactive display and content based (shape searching) retrieval of 3D data and for image based 3D modeling of complex environments. The systems have been used to scan and prepare accurate 3D models of archaeological and ethnographic collections, archaeological sites, buildings, paintings, sculptures and natural history specimens for archival documentation, research, conservation, and replication as well as for immersive 3D VR Theatre and web display applications.

This presentation will offer an overview of the technology and its museum and heritage applications with particular reference to the 3D examination of paintings and recording of archaeological sites.

5857-08, Session 2

Three-dimensional documentation of 'two dimensional' works of art

W. Wei, A. de Tagle, I. Hummelen, Netherlands Institute for Cultural Heritage (Netherlands)

For archiving, art historical purposes and restoration, 'two dimensional' (2D) works of art such as paintings or photographs have, in modern times, traditionally been documented using (colour) photography and/or digital imaging techniques. While current technology allows reproductions with high spatial and colour resolution, these techniques only document the 2D form and colour of the surface of the object. Surfaces also have, however, three dimensional properties which play just as important a role in determining an objects appearance and how it is perceived. Among these, surface roughness/texture and the optical properties of transparent layers are particularly important. Both determine the way light is scattered from the surface, and influence not only colour perception, but also glossiness, illusions of transparency, and depth perception. These properties are often the first to be affected before colour changes happen or are perceived in a measurable quantity. They are difficult, if not, impossible to document using current 2D techniques, while current 3D scanners do not have the resolution necessary to document the micro-roughness of surfaces which actually determine appearance.

The Netherlands Institute of Cultural Heritage has started a multidisciplinary programme to study the effect of 3D properties of surfaces on the appearance of works of art. The combined effects of colour, roughness, and optical properties of transparent layers are being investigated in situ using standard engineering micro-roughness measurements, colour spectroscopy, and digital imaging techniques. Initial work indicates that these are excellent methods for documenting, for example, the effects of cleaning of paintings and face-mounted photographs. Combined with light scattering models, they will provide a good tool for understanding the appearance of objects, and for their conservation. Rendering models, for example, could help conservators make selections of retouching materials based on colour and texture, or varnishes based on optical properties.

5857-09, Session 2

Interferometric fringes projection system for 3D profilometry and relief investigation

V. Moreau, B. Tilkens, D. Laboury, Y. L. M. Renotte, Univ. de Liège (Belgium)

We present a new 3D full-frame profilometer based on structured laser light projection method. This device takes advantage of the polarization states splitting technique for producing and shifting multiple sinusoidal Young's interference patterns that are projected on the inspected surface. The principle of the technique is presented and we discuss about the advantages of monochromatic light projection method as a mean to overcome ambient lighting for in-situ measurement. Some results that we obtain on several pieces of the British Museum Egyptian collection are presented to demonstrate that 3D laser profilometry is a worthwhile technique for epigraphic investigations where naked-eye inspections fail.

5857-10, Session 2

Realistic realtime illumination of complex environment for immersive systems a case study: the Parthenon

M. Callieri, CNR/Istituto di Scienza e Tecnologie dell'Informazione (Italy); P. Debevec, J. J. Pair, Univ. of Southern California (USA); R. Scopigno, CNR/Istituto di Scienza e Tecnologie dell'Informazione (Italy)

Offline rendering techniques have nowadays reached an astonishing level of realism but with the cost of a long computational time. The new generation of programmable graphic hardware, on the other hand, gives the possibility to implement in realtime some of the visual effects previously available only for cinematographic production.

In a collaboration between the Visual Computing Lab (ISTI-CNR) with the Institute for Creative Technologies of the University of Southern California, has been developed a realtime demo that replicate a sequence from the short movie "The Parthenon" presented at Siggraph 2004. The application is designed to run on an immersive reality system, making possible for a user to perceive the virtual environment with a cinematographic visual quality.

In this paper we present the principal ideas of the project, discussing design issues and technical solution used for the realtime demo.

5857-11, Session 2

An integrated system for measurement of 3D shape and color texture of artistic and architectural cultural assets

S. Capeleto, M. Fedel, F. Mario, L. Poletto, G. Tondello, N. Brusco, G. M. Cortelazzo, Univ. degli Studi di Padova (Italy)

An integrated system based on a TOF (time of flight) laser scanning for measuring shape and a spectro-photometer for measuring color is described and presented. The TOF rangefinder provides accurate distance measurement, up to 0.2 mm, pointing at most target surfaces (stone, metal, etc) from a distance in the 3-10 m range. The effective measurement rate is 1 KHz with a scanning angle of 45°. The laser output beam is scanned by a linearly swept mirror mounted on a rotation stage. The same mirror is used to redirect the backscattered radiation laser light on a photo detector. In order to achieve the complete 2D-3D acquisition, both range finder and spectro-photometer are mounted on a spinning platform capable of speeds of 7 deg/sec and with a minimum incremental motion of 5 microrad. The spectro-photometer measures light at 50 different points on the visual spectrum and these multiple measurements describe the combination of individual components that make up the complete colour measurement. Since the spectro-photometer interprets a series of points along the spectrum, its measurement is potentially more accurate than a measurement made by RGB cameras. The integrated system provides the software level with a matrix of voxels, better known as cloud of points, where each point contains an array of 50 spectrum values.

5857-12, Session 2

Inspection, 3D modelling and rapid prototyping of cultural heritage by means of a 3D optical digitiser

G. Sansoni, E. Redaelli, F. Docchio, Univ. degli Studi di Brescia (Italy)

The paper presents the activity carried out to perform the three-dimensional acquisition of the "Vittoria Alata", a 2m-high, bronze statue, symbol of our City, located at the Civici Musei di Arte e Storia (S. Giulia) of Brescia. The acquisition of the statue has been performed by using a three-dimensional vision system based on active triangulation, and using a non-coherent light source. This system, called OPL-3D, represents one of the research products of our Laboratory, which has been active for years in the development of techniques and systems for the contactless acquisition of free-form, complex shapes.

The study, originally motivated by the need to explore a new hypothesis on the origin of the statue, led to its complete digitisation and to the description of the statue in terms of both polygonal and NURBS-based models. A suite of copies of the whole statue has been obtained in the framework of the collaboration between the Direzione Civici Musei di Arte e Storia of Brescia and EOS Electro Optical Systems GmbH, located in Munich, Germany. As a first step, the 30 cm-high replica of the whole statue has been produced using a low-resolution triangle model of the statue (3.5 millions of triangles). This model was obtained by suitable compression of the original one. As a second step, two 1:1 scaled copies of the statue have been produced. For them, the Laboratory has provided the high resolution STL file (16 millions of triangles).

The paper discusses in detail the hardware and the software facilities used to implement the whole process, and gives a comprehensive description of the results.

5857-13, Session 2

3D MADMAC system: optical 3D shape acquisition and processing path for VR application

R. Sitnik, M. Kujawinska, Warsaw Univ. of Technology (Poland); M. Waglowski, ART@FACTORY (Poland)

This paper presents a full processing path from 3D-object scanning to its virtual representation with special focus on virtual museum application. Measurement technique is based on opto-numerical approach using structured light projection. Processing path consists of three main steps: filtering and preparing 3D-clouds of points, merging of directional measurements by local co-ordinate spaces unification and transforming from cloud of point representation to triangle mesh with photorealistic texture. The applicability of this path for objects with mixed diffusife-reflective surfaces and very complex shape is shown at an example of results of measurement session in Castle Kórnik. The where the main goal of the session was 3D digitizing of several cultural objects such as armours, bas-reliefs, sculptures and many more. The application of these full 3D models (including geometry and texture) in creating of virtual museum is presented.

5857-37, Session 2

Optical micro-profilometry for archaeology

R. Fontana, M. C. Gambino, Instituto Nazionale di Ottica Applicata (Italy); C. Mazzotta, Univ. degli Studi di Lecce (Italy); E. Pampaloni, L. Pezzati, Instituto Nazionale di Ottica Applicata (Italy)

A quantitative morphological analysis of archaeological objects represents an important element for historical evaluations, artistic studies and conservation projects.

Digital models, carried out from three-dimensional surface surveys, find their application for the analysis of the artwork condition, for supporting restoration interventions, for assembling 3D catalogues and archives, for planning the restoration intervention, for monitoring the various phases of the repair process, for virtual reality applications and for making no-contact moulds. Moreover, the difference between high-resolution 3D surveys taken at different time makes it possible to monitor the object shape variation.

At present, a variety of contact instruments for high-resolution surface survey is available on the market, but because of their invasivity they are not well received in the field of artwork conservation. On the contrary, optical testing has seen a successful growth in last few years due to their effectiveness and safety.

In this work we present a few examples of application of high-resolution 3D surveys of archaeological objects for diagnostics.

Measurements were carried out by means of a micro-profilometer composed of a commercial conoprobe mounted on a scanning device that allows a maximum sampled area of 280280 mm2.

The instrument has a quota resolution of about 1 μm, a maximum transverse resolution of about 20 μm with an accuracy better than 6 μm. The measurement range is ± 4 mm and the working distance is about 40 mm. The whole system is computer controlled and the acquisition speed ranges from 100 to 400 points/s, depending on scanning parameters.

A large variety of object were analysed, and a few of them are presented herein. Measurement and roughness calculations were carried on selected small areas, representative of the differently degraded surface, of an ellenestic bronze statue to document the surface corrosion before restoration intervention started. Two highly-corroded ancient coins and a limestone column were surveyed to enhance the relief of inscriptions and drawings for dating purposes.

High-resolution 3D surveys, beyond the faithful representation of objects, make it possible to display the surface in an image format that can be processed by means of specialized softwares. The application of digital filters as well as rendering techniques easies the readability of the smallest details.

5857-15, Session 3

Modì: a new mobile double-pulse LIBS instrument for standardless in-situ analysis of cultural heritage (Invited Paper)

G. Cristoforetti, S. Legnaioli, V. Palleschi, L. Pardini, A. Salvetti, E. Tognoni, Istituto per i Processi Chimico-Fisici/CNR (Italy)

No abstract available

5857-16, Session 3

Quantitative elemental analyses of archaeological materials by laser-induced breakdown spectroscopy (LIBS): an overview

V. Lazic, F. Colao, R. Fantoni, V. Spizzichino, L. Fornarini, ENEA (Italy)

LIBS is one of the most promising techniques for rapid, in-situ elemental analyses of artworks. It does not require sample preparation, it is almost non destructive (micro sampling) and information both about major and trace elements could be obtained contemporary. LIBS has been used to recognize the elements present in different archaeological materials and has been also proposed for on-line monitoring during the object cleaning by lasers. Quantitative determination of the material composition can supply useful information to restorers and help the object cataloguing. However, the analytical LIBS measurements on the archaeological materials were rarely reported, mainly due to difficulties to obtain the corresponding matrix-matched standards, required for the initial calibration. Alternatively, Calibration-Free (CF) approach could be used on some class of materials if all the major elements are detected and if the laser plasma preserves the material stochiometry. The latter condition is sometimes missing, as in the case of bronzes under nanosecond pulse laser ablation. Here, we have developed a theoretical model for laser ablation of quaternary copper alloys, which allows for correction of the missing plasma stochiometry in CF approach. The model also predicts the optimal calibration for this type of material. In our recent work, we also obtained quantitative LIBS results on marbles by realizing the calibration standards starting from doped CaCO3 powders and by applying the corrections on the plasma parameters, different for the standards and marbles. Semi-quantitative LIBS results have been also obtained on multi-layered renaissance ceramics by subtraction of the contribution to plasma of each ceramic layer.

5857-18, Session 3

Spatially resolved pigment identification by reflectance spectroscopy

P. Boher, C. Thibierge, M. LUET, T. Leroux, ELDIM (France); M. Elias, Univ. Pierre et Marie Curie (France)

Pigment identification by diffuse reflectance spectroscopy has been developed recently. Main advantages are that the measurements are non invasive, without any contact, and can be implemented in-situ without moving the work of art of its conservation place. Measured spectra are compared with a database of dry mineral pigments and best matches are proposed to restorers. The surface state of the pictorial layer and the occurrence of a varnish can be also taken into account. Recently, the analysis of pigment mixtures by incoherent multiple scattering theory make this technique suitable for a great number of practical configurations.

To make this type of analysis, fiber optics setup in backscattering configuration is generally used. The measurement spot size is quite large (several mm2) and the transmission of the optical fibers can be affected when the optical head is moved in front of the painting. In the proposed paper we present a new commercial measurement head that integrates all the component required for diffuse reflectance spectroscopy. The illumination is made with an halogen lamp and the detection by an imaging spectrograph with a Peltier cooled CMOS camera. A dedicated optical setup allows simultaneous analysis along one direction. Each measurement spot size is less than 500µm2 and up to 32 points can be analyzed simultaneously along a line of 16mm. In this way, comparative analysis can be easily done in a region of the painting. A 2D cartography can also be done by translating the instrument along one direction. In the paper, we will present all the technical details concerning this new instrument and some results obtained in different configurations.

5857-19, Session 3

Non-destructive identification of varnishes by UV-fluorescence spectroscopy

M. Thoury, M. Elias, J. M. Frigerio, Univ. Pierre et Marie Curie (France)

Qualitative UV-fluorescence of varnishes is commonly used to locate repaints on paintings or to specify the homogeneousness of a varnish layer. Photographers can now use flash UV-lamps coupled with a CCD camera to obtain colour images of the fluorescence of paintings, unveiling thus both interest and difficulty to interpret these colours.

Starting from this point of view, UV-fluorescence spectra appear to be a potential technique to characterize the nature of varnishes and, if possible, their state of degradation. This identification will be non-invasive, without contact and obtained in real time, as the identification of pigments or dyes by reflectance spectrometry which is already done in our group. The last goal will be to realize both identifications with the same set-up.

Excitation and emission fluorescence spectra are implemented with the Jobin Yvon Fluorolog-3 providing an incident wavelength between 200 and 850 nm. The excitation spectra are recorded with spectrometer Triax 320

coupled with a photomultiplier. The emission spectra are implemented optical fiber linked to a Jobin-Yvon spectrometer HR460 and a multichannel CCD detector.

In a first step, the different constituents of classical varnishes and resins have been separated by a HPLC technique coupled UV/VIS absorbance detector. Then the fluorescence spectra of each element have been collected in a data-base. In a second step, popular, fresh, raw or dissolved varnishes used between the XVI th and the XIX th century, like mastic, dammar and sandarac resins, provided by different suppliers, have been studied. The final step will be to do the same study on artificially aged varnishes by heat or UV radiations. A synthesis of the results will be presented with the aim of characterizing each varnish and quantifying their state of degradation by their fluorescence spectra.

5857-20, Session 4

The Madonna of the Yarwinder: a case study of non-invasive technique for art historians and conservators

C. Frosinini, R. Bellucci, Opificio delle Pietre Dure e Laboratori di Restauro (Italy)

Leonardo da Vinci occupies a unique place in the history of human endeavour. His life and works attract insatiable public interest and are subject to a major research industry. But how can we re-cast the whole concept of a encompassing research on his artistic technique, within a framework that takes advantage of all the available technologies?

The case-study of the Madonna of the Yarwinder is an example of a comprehensive methodology and program of non invasive analyses to study Leonardo's technique.

Focusing the uniqueness and fragility of the artworks, which is often aggravated by their age, and preventive conservation considerations, the portability of the instruments is a primary demand when undertaking an extensive research. "In situ" examination minimizes risk assessment and therefore awards the non-destructive character of the chosen methodology.

This is why non-destructive techniques play a predominant role among a huge number of diagnostic physical methods of analysis and micro analytical techniques.

Beginning with the mapping of both the structure and the painted surface, step by step, going in depth, the program of analyses passes from the characterization of areas to the localization of meaningful points that are chosen on the ground foundation of the area analyses; the elaboration of the results obtained in the imagining, focuses specific problems and raises up specific questions; the capability of modern visualization tools allows to integrate and cross-correlate all the analysis done, possibly by mapping all imaging results on a three-dimensional representation of the artwork; the final step of the research will be a set of punctual analyses which will try to provide answers to the above mentioned questions and build new hypotheses.

5857-21, Session 4

2D and 3D optical diagnostic techniques applied to "Madonna dei Fusi" by Leonardo da Vinci

R. Fontana, M. C. Gambino, M. Greco, L. Marras, M. Materazzi, E. Pampaloni, A. Pelagotti, L. Pezzati, P. Poggi, Instituto Nazionale di Ottica Applicata (Italy); C. Sanapo, Instituto Nazionale di Ottica Applicata (Italy)

Optical techniques have an important role in the field of Cultural Heritage conservation, both for their safety and for their effectiveness. Among these, imaging techniques are widely used for the diagnostics of paintings. IR reflectography [1], false colour and UV fluorescence [2], are routinely applied before restoration interventions, and have become a standard tool for the study and investigation of paintings.

Also 3D optical techniques proved to be useful tools for the analysis of artworks. However, they have been traditionally applied mainly to statues [3], architectures, archaeological finds, but rarely to paintings, because only with the recent evolution of more accurate systems, the 3D measurement of painting surfaces was able to reveal many and interesting aspects.

Moreover, the simultaneous use of both 2D and 3D techniques allows to gain additional information which is useful for studying the conservation state of a painting.

2D data can be effectively integrated into the 3D digital model of the artwork, thus creating a more complete package of information about the opera. Referencing the results of the imaging techniques on the 3D model of the painting, usually boosts the legibility of the various datasets, and allows far easier comparisons. This possibility is highly appreciated by the art historian or the conservator who is studying the object. We can surely affirm that the process of integration leads to a better knowledge of the object under investigation from both a qualitative and a quantitative point of view.

In this work we present the 2D and 3D data integration of measurements performed on the panel painting "Madonna dei fusi" by Leonardo da Vinci. The imaging analysis was carried out by applying infrared reflectography, colour and false colour imaging, and ultraviolet fluorescence. The IR reflectogram, the false colour and the colour image are simultaneously acquired with a scanning device characterized by a high resolution (4 points/mm), a high tonal dynamic (few thousands grey levels) and point-to-point correspondence between these three images. A multi-spectral device, based on a high-resolution CCD camera, is used for UV fluorescence imaging. The 3D relief is obtained by means of a laser scanning micro-profilometer with a quota resolution less than 1 micron.

5857-22, Session 4

Fibre optic reflectance spectroscopy and hyper spectral image spectroscopy: two integrated techniques for the study of the "Madonna dei fusi"

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Reflectance spectroscopy supplies fundamental information for investigating art objects and diagnosing their state of conservation. Until recently, reflectance spectra could be measured only on samples taken from the art objects. Recent progress in fibre optics reflectance spectroscopy (FORS) and image spectroscopy (IS) has made it possible, however, to perform non-invasive measurements. Moreover, the two techniques can supply data in large enough quantities as to make the use of sophisticated statistical methods significant for detecting variations due to ageing and degradation. FORS and IS are, in a sense, complementary techniques as the former provides spectrally extensive information on single points, while the latter provides 2-D maps from which the reflectance spectrum of each pixel can be displayed. Both FORS and IS were applied in the case study on the Madonna dei fusi. In particular, IS was realised by means of a hyper-spectral scanner recently assembled at the "Nel!

lo Carrara" Istituto di Fisica Applicata. The characteristics of the scanner are: 0.1 mm spatial sampling over a 1x1 m2 surface and ~1 nm spectral sampling in the wavelength range from 400 nm to 900 nm. The information provided by these two techniques was consistent with what supplied by the non-invasive techniques employed by the other teams participating in the case study, in particular as regards the pigments, the preparatory layer, the binding medium, and the previous restoration works.

5857-23, Session 4

Tools for inverse mapping and visualization of multi-spectral image data on 3D scanned representations of drawings

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A new prospective for the study, documentation and presentation of Cultural Heritage is opened by the joint usage of the tools for the automatic reconstruction of digital 3D models and the instruments for interactive 3D visualization. New techniques are available to perform high-resolution sampling of both the shape and the multi-band reflection properties of painted surfaces. The digital 3D models produced are extremely accurate and rich of information, as it has been proved in the experiments run on the Leonardo's Madonna of the Yarnwinder. This paper presents an overview of the techniques needed to build high-quality 3D models from the raw data produced by the scanning devices and describes how to process those models to make them usable in interactive applications. A very critical point is how to integrate the reflection properties with 3D shape models; this integration (based on texture mapping) allows us to produce textured 3D models that allow a joint visualization of shape and color attributes. The interactive visualization tools developed by ISTI-CNR are described, presenting both their features and potential for the visual presentation and analysis of works of art. Examples of the results obtained on the Madonna of the Yarnwinder are presented.

5857-24, Session 4

Non-invasive midFTIR characterisation of organic materials in the Madonna dei Fusi by Leonardo da Vinci

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Contrary to the non-invasive identification of inorganic pigment, the identification of organic media and varnishes without sampling is still very challenging. Recent advances in mid infrared fiber optic technology have made vibrational spectroscopy in reflectance mode very promising for the

in situ non-invasive detection and identification of organic compounds on the surface of paintings. The present study illustrates the use of non-invasive midFTIR reflectance spectroscopy for the characterization of organic materials in the Madonna dei Fusi by Leonardo da Vinci.

The characterisation of the surface by punctual mid infrared reflectance spectroscopy has revealed that the thick and uniform varnish layer covering the whole painting is probably an oil resin varnish made with an emulsion of terpenic resin in a drying oil. The presence of synthetic resins can be excluded.

The thick varnish layer stopped the mid infrared radiation from reaching the inner layers and therefore it has not been possible to obtain definite information on pigments and binders making the painting. Nevertheless, the band pattern at 1510 and 1645-1630 cm-1 suggests the use of protein materials as binders while the combination bands at 2500 and 1800 cm-1 proves the presence of calcium carbonate.

Given that no samples were collected, these results are very promising even if limited to the varnish layer. To better understand the composition of the paint layer, it is desirable that more non-invasive midFTIR testing can be done if and where the varnish is removed/replaced.

5857-25, Session 4

Composition and stratigraphy of the paint layers: investigation on the Madonna dei Fusi by ion beam analysis techniques

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Ion Beam Analysis (IBA) techniques are a powerful tool to investigate the composition of a material in a fully non-invasive way. This is performed by collecting and discriminating in energy the characteristic radiation emitted by the atoms and nuclei of the object to be analysed, which is used as a target for a beam of accelerated particles.

Among IBA techniques, Particle Induced X-ray Emission (PIXE) and Gamma-ray Emission (PIGE) exploit the X-rays emitted by the atoms and gamma-rays emitted by the target nuclei, respectively. In the past twenty years, these techniques have been extensively and successfully applied in many fields of art and archaeology, thanks in particular to the possibility of using an external beam set-up, which guarantees no damage to the analysed works; however, only in very few cases they had been used for the analysis of paintings on canvas or wood, and the investigation with IBA techniques of the Madonna dei fusi has been probably the most extensive study of this kind so far performed on a work of great artistic relevance.

It should be recalled that IBA techniques do not provide direct imaging of the analysed works but only compositional spot analysis; however, because of the high cross section values of the induced processes of radiation emission, a single measurement takes only few minutes at most, making thus possible the analysis of a large number of spots in a short time. This way, previous results from imaging techniques can be used as a guide for selecting the areas of major interest (e.g., for a painting, spots of inhomogeneous optical or IR response, or local anomalies in the vertical profile, etc.), on all of which the compositional analysis can then be performed with IBA. This was in fact the case with the Madonna dei fusi: at the Florence accelerator laboratory, measurements were performed by using PIXE (with a variant of it, the so-called differential PIXE) and PIGE on a large number of areas, where the preliminary studies with IR spectrometry, UV fluorescence, surface roughness analysis etc., had suggested specific problems to investigate. The analysis allowed us to characterise the pigments of original and restored areas and the substrate composition, and to obtain information about the stratigraphy of the painting, also providing an estimate of the paint layer thickness.

5857-14, Session 5

3D-μCT reveals the work processes of cast plaster statues, their internal structures, damages and restorations

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Cast plaster dries with different densities depending on the surrounding media. Liquid plaster filled into a lubricated casting mold will acquire a surface boundary of high density, once set. The second and third cast layers into the still moist form will dry to a lower density. Later additions of plaster, due to sculptural reworking and restorative measures, will also have discernible densities. With computerized tomography (CT) the density in each volume element can be measured. With 3D - μCT the total body of a sculpture can be scanned to a high spatial resolution. Cracks within and cuts through the original cast become visible along with internal structures and armouring. The results from two studies on plaster statues (by Christian Daniel Rauch and Honoré Daumier), done in support of the conservation process as well in the intent of revealing a relative chronology within a series, are presented and placed into the art-historical context.

5857-26, Session 5

Dymamic signal processing and analysis in the OCT system for evaluating multilayer tissues

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Optical coherence tomography (OCT) is a promising tool for nondestructive cross-sectional evaluating internal structure of objects. In this technique, a scanning low-coherence interferometer is employed to image of an object's internal structure when providing depth/lateral scans. Information about a tissue is represented by depth-resolved reflection and contained in value of interference fringes envelope. The problem is the light scattering by the tissue to be evaluated; it is why fringes and their envelope are often distorted. The other problem consists in a need of high-speed data processing.

A few methods to assess signal envelope are well-known like amplitude demodulation implemented by signal detection (rectification) with subsequent low-pass filtering or synchronous amplitude demodulation involving quadrature components, etc. In the former case, the filter frequency characteristic and cut-off frequency is important. In the later case, the carrier fringe frequency must be exactly known and must be stable. Usually, a band-pass analogue filter is used at input of the processing system to extract fringe signal and suppress noise influence and false (non-coherent) impulse noise. However, any filtering may introduce own distortion in evaluated fringe envelope, e.g., due to uncontrollable variation of fringe frequency caused by influence of disturbing factors.

We propose to use a stochastic fringe model and nonlinear (extended) Kalman filtering method for processing noisy low-coherence fringes [1]. Fringe model is defined by a stochastic difference equation that involves the peculiarities of fringe formation process. When processing, a stochastic fringe signal value is predicted at a next discretization step using full information available before this step, and prediction error is used for dynamic correcting the fringe envelope and phase.

To verify the stochastic filtering method, a comparative analysis of conventional fringe demodulation methods and extended Kalman filtering method was performed. In experimental research, the low-coherence fringe signals obtained when evaluating multilayer objects in the OCT system for painting diagnostics [2] were processed. The advantages of Kalman filtering method consist in its noise-immunity, adaptation to local fringe parameters, data processing speed and optimal fringe evaluation.

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5857-27, Session 5

SIRIS: a high-resolution scanning infrared camera for examining paintings

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The new SIRIS (Scanning InfraRed Imaging System) camera developed at the National Gallery in London allows high-resolution images of paintings to be made in the near infrared region (900-1700 nm). Images of 5000 x 5000 pixels are made by moving a 320 x 256 pixel InGaAs array across the focal plane of the camera using two orthogonal translation stages. The great advantages of this camera over scanning infrared devices are its relative portability and that image acquisition is comparatively rapid - a full 5000 x 5000 pixel image can be made in around 10 minutes.

The paper describes the development of the mechanical, optical and electronic components of the camera, including the design of a new lens. The software routines used to control image capture and to assemble the individual 320 x 256 pixel frames into a seamless mosaic image are also mentioned. The optics of the SIRIS camera have been designed so that the camera can operate at a range of resolutions; from around 2.5 pixels per millimetre on large paintings of up to 2.0 x 2.0 m to 10 pixels per millimetre on smaller paintings or details of paintings measuring 0.5 x 0.5 m.

The camera is primarily designed to examine underdrawings in paintings; preliminary results from test targets and paintings are presented and the quality of the images compared with those from other cameras currently used in this field. Future applications and refinements, including the use of filter sets, will be mentioned.

5857-28, Session 5

Atomic force microscopy imaging directly on paper: a study of library materials degradation.

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Atomic Force Microscopy (AFM) has been used to study fiber degradations, as they appear on paper surface, aiming -in the mid term- at assessment of a micro-destructive technique capable of providing qualitative and semi-quantitative information on deterioration and ageing.

AFM topographies of pure cellulose paper samples artificially aged were considered as well as topographies of original paper samples naturally aged showing different kind of deterioration.

Whatman N.1 chromatography paper was used as a model system to study ageing effect on sub-micron structures on cellulose fibers. Chemical and biological deterioration processes were modeled, as well, by mean of artificial degradation treatments, following the criteria of reproducing effects frequently isolated from library materials.

The effects of chemical reaction induced by accelerated ageing in climatic chamber (80°C, R.H. 65%) on paper surface, and the effects of a fungal attack reproduced in vitro inoculating paper samples with Aspergillus terreus Thom (6000spores/100μl, 27°C, R.H. 100%) were evaluated by means of Atomic Force Microscopy imaging, and spectrophotometric measurement in the UV-Vis-NIR.

In order to map structure local properties, morphological variations repeated with statistical relevance were correlated to chemical, biological and spectroscopic characterization.

Information achieved from such analysis is then used for a comparison with measurements of naturally aged paper, providing insight in analysis and classification of typical phenomena, like yellowing and foxing stains, usually affecting valuables in libraries.

5857-29, Session 5

Optical coatings on glass for preserving artworks from illumination induced damage

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The electromagnetic radiation coming from both natural and artificial illumination sources causes damage of artworks displayed in museums and galleries. The usual approach, for reducing damage, consists in lowering the illumination intensity and shortening the lighting duration. The most commonly observed deterioration effects, induced by illumination, are: color fading of paintings, browning of white paper, cracking of the painted surface. Some plastic sheets for museum applications, able to block the ultraviolet radiation, are available on the market but this is not sufficient to protect artworks, because damage is induced also by visible and infrared radiation. The optical method proposed here consists in the use of special multilayer coatings, deposited on glass, able to block both the ultraviolet radiation and part of the visible radiation not useful for viewing, and also to attenuate the infrared. Moreover the same coating should improve the vision in respect to the uncoated glass. In fact, the uncoated glass, although is useful for protection against vandalism, gives reflection effects that disturb the observer.

In this work some coated glasses are realized following the above mentioned criteria, then their performance is analyzed in respect to both the radiation blocking, outside the range of sensitivity of the human eye, and the possible alteration of the perceived color, in fact color rendering is a crucial point for art application. Classical photometrical and colorimetrical tests were carried out to investigate the effect of these coated glasses positioned in front of painted samples: transmittance, reflectance and colorimetric data were measured, taking great care of the color differences between samples covered alternatively with the coated or the uncoated glass. In addition, psychophysical tests were performed; the ability to discriminate colors was tested, in order to preserve a normal color perception. Results of the application of this innovative technique on both painting protection and color rendering are reported.

5857-31, Session 5

Spectral and colorimetric characterisation of painted surfaces: a scanning device for the imaging analysis of paintings

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Multispectral analysis has successfully been growing in the last few years as a tool for painting investigation. The technique consists in irradiating the paint surface with radiation on the visible and near infrared spectral region, and in detecting and analysing the diffused radiation within narrow spectral intervals with a suitable device. The multispectral analysis allows spectral and colorimetric characterization of the painted surface and it is used to document the conservation state of the artwork as well as to identify the materials composing the painted surface.

In this work we present a scanning device for contact-less and single-point measurements of the spectral reflectance factor. Two low-voltage halogen lamps put at 45o to the normal to the painting surface irradiates a small area of nearly 5 cm2 of diameter. The back-scattered radiation is gathered by an optical system and it is focused on the termination of a multimode optical fibre that carries the collected light to the detector. This latter is a photomultiplier array equipped with 32 interferential filters covering the 380800 nm spectral range with 10 or 20 nm central-wavelength spacing and 10 nm full width at half maximum. The device has a high tonal dynamic due to the 12 bit A/D conversion. The scanning system is composed of an XY motorized translation stage which allows to scan a surface of nearly 1 m2 with a spatial resolution of 16 pixels/mm2. An adjustment procedure was established and calibration was performed by means of a set of 7 matt ceramic colour standard certificated by National Physical Laboratory (UK). Multispectral analysis was performed on a few paintings that are under repair at the Opificio delle Pietre Dure laboratory in Florence, and spectrophotometric results are shown.

5857-32, Session 5

X-ray computed tomography of an ancient big globe

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Introduction.

Computed tomography (CT) is a powerful nondestructive technique, which provides high resolution images of the internal structures of the investigated objects. CT is very useful in the cultural heritage field, since it could give information about part of objects not accessible. In this paper we present a CT study of an ancient large globe created by a Dominican monk around 1567 and located in Palazzo Vecchio, at Florence. A restoration project is ongoing, for returning the globe to its original magnificence. Within this project, a CT of the globe was achieved, for exploring the nature and the conditions of the inner structure.

Materials and methods.

The CT system used consists of an X-ray tube, mounted on a vertical moving axis, a planar detector composed of a GOS scintillator screen and an Electron Bombarded CCD camera, which can translate both horizontally and vertically, and a rotating platform, on which the globe was placed. The main problem of getting a complete CT is related to the large size of this masterpiece (220 cm in diameter) and the need of achieving an in situ analysis in a museum surrounded by visitors. The dimension of the planar detector used was 30Å~40 cm2, thus requiring the acquisition of about 50,000 images, for covering the entire field of view.

Results.

The 3D CT reconstruction of the globe clearly shows the entire inner structure, consisting of a central pole, 8 bars as 2 tetrahedrons and 30 meridians. All the inner structure is made of iron, with a total weight of about 350 kg, estimated from the segmented 3D reconstruction.

5857-33, Session 5

Optical Coherence Tomography: a non-invasive technique applied to paintings conservation

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Optical Coherence Tomography (OCT) is an optical interferometric technique developed for in vivo imaging of the eye and biological tissues. OCT is essentially a scanning Michelson's interferometer with a 'broad-band' source that has the spatial coherence of a laser. The low temporal coherence and high spatial concentration of the source are the keys to high depth resolution and high sensitivity 3D imaging. The technique is non-invasive and non-contact with a typical working distance of 2 cm.

It is current practice to take tiny samples from a painting to mount and examine in cross-section under a microscope. However, since conservation practice and ethics limit sampling to a minimum and to areas along cracks and edges of paintings, which are often unrepresentative of the whole painting, results from such analyses cannot be taken as representative of the paintings as a whole. Recently in a preliminary study, we have demonstrated that near-infrared OCT can be used directly on paintings to examine the cross-section of paint and varnish layers without contact and the need to take samples. This non-invasive technique enables cross-sections to be examined anywhere on a painting. In this paper, we will report new results on applying near-infrared en-face OCTs to paintings conservation and extend the application to the examination of underdrawings, drying processes, and quantitative measurements of optical properties of paint and varnish layers.

Thursday-Friday 16-17 June 2005

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5858-01, Session 1

Micro-optics measurement techniques and instrumentation in the European network of excellence on micro-optics (NEMO)

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The measurement and characterization of micro-optical elements, system and materials concerning all aspects like shape, displacement, deformation, strain / stresses, material constants, chemical composition etc. is a huge area which requires extended, multidisciplinary knowledge and wide range of expensive instrumentation. The NEMO Centre for Measurement and Instrumentation includes twenty four organisations which measurement expertise and capabilities cover nearly all important measurement and characterisation methods and a big pool of commercial and internally developed instrumentation.

The paper presents the main tasks of the Centre including: providing benchmarking of the instrumentation and analysis software, providing measurements and integrated pool of equipment for characterisation of materials and optimising of new technologies incl. replication, mastering and packaging,

identifying the gaps in measurement capabilities of existing equipment and providing the guidance for development of new measurement methods and instrumentation, development of proof-of principle demonstrators of novel measurement systems based on classical and micro-optics concept and technology and collaboration with virtual Centre of Modelling in order to develop numerical-experimental methods supporting novel micro-optics development

The paper gives also the review of the NEMO partners' expertise in micro-optics measurement and characterization with the emphasis on such problems as: microlens arrays testing, waveguide and fibre optics characterization, static and active microelements measurements, 3D refractive index distribution determination, subwavelength structures characterization and shape monitoring and strain distribution testing in micro-optics packages. Also the interesting issues connected with determination of the optimised measurement chains, data analysis and standarization of measurement procedures are mentioned.

The future structure of the Centre with the wide access to a virtual library of experimental data and the integrated NEMO's partners pool of instrumentation which will be obtained directly (on site), remotely (by internet) or by full services performed by the Centre is also briefly discussed.

5858-02, Session 1

International standards for metrology of microlens arrays

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Though a microlens and microlens arrays are important device in the electronic and optical field, users and suppliers were augmented with tough negotiations for every individual product business without standardization progress in the expanded market.

Since even the definitions of terms and dimensions were different with every supplier, it was caused difficult to find a second vendor. Also, it has obstructed the market expansion.

In order to overcome such a situation, microlens and microlens arrays international standards were started to discuss in 1996 at ISO/TC 172/SC 9 Glasgow (Scotland) meeting. Finally, "ISO 14880-1: Microlens Arrays part 1-Vocabulary" was published in August in 2001. Following the publication of ISO 14880-1, the working group of ISO/TC 172/SC 9 continues to develop new standards for testing properties of microlens arrays.

Part 1-Vocabulary standard describes the terminology of each feature of microlens and microlens arrays. Many specified terminology is used in this standard. We need to define the test methods of each specified terminology clearly in the following new standards, which covers optical properties and geometrical properties.

I will report the recent status of these microlens and microlens arrays international standards and the progress of test methods for optical properties and geometrical properties. Especially, I will report a recent wavefront aberration test methods using a phase shift method applied to the Mach-Zehnder interferometer for microlens, less than 30 micrometers in diameter.

5858-03, Session 1

Real-time in situ sag characterization of microlenses fabricated with deep lithography with protons

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Today different technologies exit that allow the fabrication of individual high-quality micro-optical refractive components [1] and more in particular spherical microlenses. In this paper we will focus on the fabrication and characterization of the latter components obtained with Deep Lithography with Protons (DLP). The concept of this DLP process is based on the fact that protons, which penetrate a sample made of linear high-molecular-weight PMMA, will split the long polymer chains [2]. Afterwards the irradiated sample is placed in a monomer vapour inside a reactor causing a considerable expansion of the irradiated volume, which for circular footprints will result in hemi-spherical surfaces or spherical microlenses.

In the past we first fabricated the DLP microlenses and secondly a full geometrical and optical characterization was performed. However, this working method was very time consuming due to the amount of experiments needed for a complete calibration of our fabrication process. Therefore, we developed an interferometer for a real-time in situ sag characterization of the microlenses. In a first step we built a Mach-Zehnder interferometer working in the visible wavelength range and demonstrated its proof-of-principle for the determination of the lens sag for both diffraction-limited as well as non-diffraction-limited microlenses. In a next step we then transferred the concept of this interferometer to the closed reactor in which the in-diffusion of monomer vapour in the irradiated zones takes place. This novel approach allows us to continuously monitor the volume expansion of the desired areas until spherical microlenses with specific lens sag are fabricated. At the conference we will show the latest results we obtained on the real-time in situ monitoring of in-house DLP fabricated microlenses.

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5858-04, Session 1

Interferometric method for measuring the refractive index profile of optical waveguides directly written in glass substrates by femtosecond laser

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Direct waveguide writing by femtosecond lasers is rapidly becoming a promising valid alternative to standard fabrication techniques. Significant research efforts are devoted for to understanding the effects of interaction of the radiation with the material and determining the key parameters in the writing process. The assessment of a reliable fabrication process depends crucially also on the availability of high resolution inspection and measurement methods. In this paper we employ digital holography (DH) in a microscope configuration as the characterization tool for measuring the refractive index profile of the waveguides. The method offers the advantages of high spatial resolution, high sensitivity and it allows to determine an absolute value of refractive index change without the need of any calibration. We report on the optical characterization of optical waveguides operating at 1.5 micron wavelength in two commercial glasses written by a stretched-cavity femtosecond Ti:sapphire oscillator. Measurements made by DH has have evidenced a strong dependence of the fabrication process on the type of the glass substrate.

5858-05, Session 1

Application of photoelastic tomography to measurement of stress in optical microelements

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Mechanical stresses are present in every optical or photonic element and they are responsible for inducing of anisotropy in element.

In this paper we implement method which relies on multidirectional measurement of object birefringency (using photoelasticity algorithms) followed by procedures of optical tomography.

Object is analysed in circular polariscope; the specimen is placed in an immersion tank and a beam of polarized light is passing trough the specimen. Using methods of phase shifting technique in integrated photoelasticity characteristic retardation D of object is computed. Measurement of birefringency relies on acquisition of 6 images of light emergent from circular polariscope for various positions of second quarter

wave plate and analyzer. Then, axial stress is calculated using inverse Radon transform of the retardation function:

σzz =λ/2πC iradon{ Δ(x,α)},

where: λ - wavelength, C - photoelastic constant, Δ - characteristic retardation, α - angular position of object and x - linear transverse coordinate.

In this paper we verify the correctness of this algorithm for measurement of small object, like Panda polarization maintaining fiber. At first we simulate the process using mathematical model of object and light propagation. Computations will be performed using full vector propagation method. The results of simulations are compared with actual measurement results derived from physical setup.

5858-06, Session 2

Near-field characterization of millimeter long waves guiding structures using a high-accuracy optoelectronic control system holding the sample

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We present a near field characterization of millimeter long wave guiding structures (Y junction, Multi Modes Interference coupler) using a high accuracy home-made sample holder. The principle of this experiment is based on an atomic force microscopy tip that is brought to the surface of the sample (in the near field zone) in order to coupled out a small amount of the light confined inside the wave guiding structures. Due to the size of the components, scans as long as a few millimeters are required to get an entire optical mapping of the structure [1]. With the commonly available equipments such a scan is performed by acquiring step by step more than 100 images. for a 2 mm scan. The overlapping of the different images is time consuming and unsatisfactory unless a numerical stiching procedure based on topographical details is used. Effective refractive indexes are typically determined with a precision of 10-3 which could be further improved by increasing the millimeter scan resolution. The reason why successive images do not overlap is mainly due to the mechanical system supporting the sample. Actually, the nonlinearity of the actuator and the thermal expansion of the mechanical part prevent us to reach nanometric scale of repeatability on the positioning for micrometric range of displacements. In order to enable long range scans with nanometric repeatability and accuracy, we develop a specific mechanical system controlled by a heterodyne interferometric apparatus and a home-made high frequency electronic board [2]. The position of the sample is measured in real time with a resolution of 0.3 nm. The servo-loop allows to control the position of the sample with a repeatability of 1 nm (1 ) for a displacement of 1 mm. Furthermore our method is insensitive to the nonlinearity of the actuator.

5858-07, Session 2

Surface refractive index mapping by use of near-field optical microscopy.

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Knowledge of the surface refractive index distribution is very important in many modern branches of science such as integrated optics and fiber optics (since optical waveguides properties such as mode profile, dispersion, and cut-off wavelength can be investigated from it). There currently exists a range of methods for the investigation of refractive index profiles of optical fibres and waveguides, for example, studying the light scattered by a fiber, or the quantitative phase microscopy technique and other methods.

In this report the application of the near-field optical microscope (SNOM), acting in collection / illumination mode, to refractive index profiling of optical fibers is demonstrated. Near-field optical images of the refractive index distribution along the cleaved edge of optical fibers are obtained and analysed for different fiber tips. Finally, the possibilities and limitations of SNOM imaging for the characterization of optical fibers are discussed.

5858-08, Session 2

Compact confocal microscopy

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Within the framework of the ESA General Support Technology Program, a compact dedicated confocal laser scanning microscope has been developed for 3D fluorescence imaging of biological samples.

The microscope permits normal confocal mode operation with excitation at 488nm and fluorescence lifetime imaging (FLIM, time resolution 200ps) with excitation at 630nm. Each fluorescence signal is detected by a dedicated photomultipier tube. Proper optical signal separation and filtering is performed by a set of optical filters and dichroics. The software and hardware further include the specific imaging modes allowing for fluorescence recovery after photobleaching (FRAP) and fluorescence loss in photobleaching (FLIP).

In addition to this dual wavelength fluorescence imaging mode, the microscope includes transmission imaging capabilities via differential imaging contrast (DIC). Both fluorescence and DIC imaging can be acquired simultaneously. The source for the DIC is a near infrared LED. This choice permits the decoupling of DIC and fluorescence signals by a dichroic cold mirror. The DIC interference is created by a combination of Wollaston prisms in conjugated planes. Contrary to most commercial DIC designs, the interference is performed in the back focal plane of the microscope objective with a standard Wollaston prism (where most of the time Nomarsky prisms are used).

The field of view is 450μm x 450μm maximum divided in 1024x1024 pixels. The optics chosen for the microscope objective and tube lens system both from Zeiss, yield a compact inverted microscope system. The microscope objective is a 40X water immersion type with NA = 0.8, with coverslip correction. The opto-mechanical assembly is constructed on the two sides of an aluminum base plate of dimensions 389 mm by 575.5 mm, 16mm thick. The total volume under covers is 53 dm(c)¯, excluding PC and control electronics.

In this paper, the design, performance and limitations of the compact confocal microscope are discussed. Illustrative examples of applications on biological samples are shown.

5858-09, Session 2

Comparison of different approaches for modelling microscope images on the basis of rigorous diffraction calculation

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High resolution optical microscopy is still an important instrument for dimensional characterisation of micro- und nanostructures. For precise measurements of dimensional quantities a high quality modelling of the optical imaging on the basis of rigorous diffraction calculation is essential, which account both for polarisation effects and the 2D or 3D geometry of the structures.

Some applications like for example the measurements of line widths on photomasks demands for measurement uncertainties of few nm or less. For these requirements the numerical and the model induced uncertainty, respectively, may be limiting factors even for sophisticated modelling software.

At PTB we use two different rigorous grating diffraction models for modelling of the intensity distribution in the image plane, the rigorous coupled wave analysis (RCWA) method and the finite elements (FEM) method. In order to evaluate the performance of both methods we performed comparative calculations on the basis of a test suite of binary chrome on glass gratings with different line widths reaching from 100nm to 10μm, and with different line/space ratios between 0.01 and 100.

We will present results of this comparison for TE, TM and unpolarised Köhler illumination of the grating. Residual deviations between both methods and the resulting measurement uncertainty will be discussed and related to the corresponding time consumptions.

5858-10, Session 2

Two-dimensional power spectral density measurements of x-ray optics with the micromap interferometric microscope

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The interferometric microscope has become a basic metrology tool for highly accurate testing of the surface finish of X-ray optics with sub-Angstrom rms roughness. The standard list of output parameters of an interferometric microscope measurement (such as the Micromap-570) includes values of roughness averaged over an area and along a sample line. However sophisticated X-ray scattering calculations require more rigorous information about the optics. One of the most insightful approaches to the calculation is based on the two-dimensional (2D) power spectral density (PSD) distribution, allowing for the evaluation of three-dimensional distributions of X-rays scattered by the optics.

A straightforward attempt to transform the area distribution of the residual surface heights available from the interferometric microscope data file into a 2D PSD distribution fails due to the spectral distortion in the PSD caused by an unknown spatial frequency response function of the instrument.

For the case of the Micromap-570 measurement, the PSD spectral distortion appears as a significant difference between the tangential and sagittal PSD spectra deduced from the 2D PSD distribution. A detailed investigation of the origin of the anisotropy was performed that indicated

the read-out asymmetry of the CCD camera and the necessary correction of the asymmetry by the software algorithm caused the problem.

The main results of this investigation are additional software and a procedure developed for correcting the Micromap-570 2D PSD measurements. The correction employs a spatial frequency response function deduced analytically based on experimentally confirmed assumptions about the origin of the resolution anisotropy. The deduced spatial frequency response function has only one free parameter, the width of the gate-shaped apparatus function which is equal for both directions. The developed procedure has been applied to correct the 2D PSD distribution for the Micromap-570 self-test measurement, which should give a white-noise 1D PSD spectrum independent of spatial frequency. The resolution width corresponding to the best fit was found to be 1.35 pixels. The effectiveness of the correction is demonstrated with a number of PSD measurements with different X-ray optics. In particular, the developed PSD procedure was successfully applied to measure the spatial distribution of groove density of an X-ray grating.

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5858-11, Session 2

Automated fringe-pattern extrapolation for patterned surface profiling by interference microscopy with Fourier transform analysis

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Single interferogram analysis techniques with a spatial carrier like the Fourier transform method [1,2] typically allow faster acquisition rates than multiple interferogram techniques. This is an interesting feature for real-time displacement fields measurements of MEMS devices as function of an external thermal or mechanical loading, for dynamic measurements at video rate [3] and for measurements in disturbed environments like clean rooms. They also require simpler optical systems as it is no longer necessary to vary the interferometer optical path difference. However a well know issue of the Fourier transform technique is the occurrence of large phase errors when interferograms with a finite size are demodulated, notably when the numbers of fringes in horizontal and vertical directions are not integer values. This is particularly critical for surface profiling of MEMS devices that typically include parts with a very small area. A well known technique to reduce these artefacts is the use of fringe extrapolation by using the Gerchberg algorithm [4,5] and, in some cases by using apodizing functions in the space domain. Briefly, the Gerchberg algorithm is an iterative processing that replaces areas without fringes, or with fringes having a low modulation, by fringes computed by an inverse Fourier Transform of the filtered spectrum of the whole interferogram. In addition the real fringe pattern intensity distribution is retrieved in areas with a high fringe contrast. In this work we investigated performances and automation of the Gerchberg technique combined with Fourier transform phase demodulation in the case of interferometric measurements on surfaces with small-size patterns or/and cuttings. Different filter shapes in the Fourier space were tested for the determination of valid areas in the interferogram, for the fringe extrapolation stage and for the final phase demodulation. Simulated interferograms or real interferograms recorded on micromechanical devices by interference microscopy were used for this evaluation. Filter shapes investigated include rectangular and circular filters with a binary or cosine shape intensity profile, "adaptative" filters with a shape computed by thresholding the modulated fringe carrier lobe and "extended" filters. Results were evaluated by several criterion such as the normalized value of the modulated carrier peak, the intensity of artefacts in the Fourier spectrum related to fringe truncation, the ratio of integrated spectral intensity within and outside the modulated carrier peak and the phase errors after demodulation.

For the determination of interferogram valid areas from, a filter of the modulated carrier lobe extending to high spatial frequencies was found necessary to avoid rounding of pattern corners. The best results were obtained by using this processing and "adaptative" filters both for the fringe extrapolation step and for the phase demodulation step. In most cases fringe extrapolation with only 10 iteration steps were found sufficient to obtain a good accuracy. The whole process could be fully automated with a reduced set of parameters.

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5858-29, Poster Session

Manufacturing and testing of x-ray imaging components with high precision

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In the latest 20 years,x-ray imaging technology has developed fast in order to meet the need of x-ray photo-etching, spatial exploration technology,high-energy physics,procedure diagnosis of inertial confinement fusion(ICF),etc.Since refractive index of materials in the x-ray region is lower than 1,and x-ray is strongly absorbed by materials, the characteristics of x-ray increase greatly difficulty to obtain x-ray image. Conventional imaging methods are hardly suitable to x-ray range.In general,grazing reflective imaging and coding aperture omaging methods have adopted more and more.

We have designed a non-coaxial grazing reflective x-ray microscope which is composed of four spherical mirrors,in order to satisfy the requirement of the diagnosis of inertial confinement fusion(ICF).The four mirrors have the same size. The radius of each mirror is 29500mm and the aperture is 30mm*20mm.Allowable tolerance of the radius is lower than 0.2% and one of surface roughness(rms)is lower than 0.6nm.Evidently it is very difficult to fabricate such mirrors.

in order to obtain eligible mirrors,we choose 18 mirror roughcasts and array them on a round disk according to 3*6 format. The combined manufacturing method can ensure high accordant quality.The fabricated mirrors are tested by both test plate and double round aperture methods.measured radius errors of the mirrors are about 40mm.The surface roughness(rms)of the mirrors is inspected by the relative interferometric equipment.The measured surface roughness is lower than 0.56nm

5858-30, Poster Session

Displacement metrology based on grating imaging with a cylindrical lens array and a phase grating

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Displacement metrology applying a cylindrical lens array and a phase grating is proposed. The proposed metrology is based on the grating imaging method, which conventionally uses two amplitude gratings with rectangle aperture of fifty percent width of the period. The first grating generates a periodic light pattern on it by illuminating with incoherent light. The second grating as a scale has a role of imaging the periodic pattern on an image plane. When the second grating relatively moves to the first grating, the periodic image also moves on the image plane. A quasi sine wave signal that is used for displacement measurement can be obtained from a photo diode array placed on the image plane.

In the conventional metrology mentioned above amplitude of the displacement signal is not sufficient for precise measurement because about seventy five percent of the light is trapped by two amplitude gratings. On the other hand, in the proposed metrology a cylindrical lens array and a phase grating are applied as the first and the second grating, respectively. Therefore, the illuminated light is trapped neither by the first grating nor the second grating except absorption.

In our experiments, a cylindrical lens array with 200 μm pitch and a reflective sine wave phase grating with 100μm are used. Experimental results demonstrate that the displacement signal by the proposed metrology has four times higher amplitude than the conventional one. We can say that more precise displacement measurement can be realized by our proposal.

5858-31, Poster Session

High-accuracy reflectometry technique and statistic measurements treatment method for refraction index determination

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Optical devices design requires accurate techniques for optical parameters determination. Photometric procedures combined with algebraic methods were applied for evaluating refraction index, absorption coefficient and

thickness of films to be used in classical and photonic optical components manufacturing; however, most of the procedures were only successful for particular determinations or in a specific spectral range and allowed accuracies to the second digit to the right of the decimal point. This precision is quite sufficient for most cases of thin-film applications; however, optoelectronics and integrated optics devices require a finest determination of the optical constants with an accuracy as great as possible.

In this work we present a method which makes possible the evaluation of the refraction index with accuracies of the third decimal digit. For this purpouse, a new cuasi-normal incidence radiometric technique (CNIRT) was implemented and combined with a specific statistic algorithm procedure for experimental values treatment. The statisc algorithm was specifically developed for measurements treatment. The proposed experimental technique is analyzed in depth and rules for high precision measurements are given. Refraction indices of soda lime and BK7 substrates were evaluated as function of wavelength and compared with the theoretical ones. In all cases accuracies of the 10-3 in refraction indices determination were obtained. Finally, and making use of high precision polished techniques, the authors are adapting the method for improving the standard techniques used in the reproduction of step and graded index profile functions and diffusion depths of integrated optical waveguides.

5858-32, Poster Session

Two methods to determination topological charge in regular net of optical vortices.

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The regular net of optical vortices generated by three plane waves interference is a base for the new kind of interferometer - Optical Vortex Interferometer (OVI). The well known problem in interferometry is unique phase reconstruction (phase unwrapping). The two independent methods, which are the subject of this communication, solves the unwrapping problem in the case of OVI. Ones the OVI is calibrated the phase can be read without ambiguity, provided the geometry of the reference waves is stable. Both methods allows determining the sign of optical vortices topological charge, which in the case of OVI is equivalent with the phase unwrapping problem. This is an important advantages of the OVI, which can be applied for various measurements in micro-optics.

5858-33, Poster Session

Optimum instrumentation of a tapping mode, non-optically regulated near-field scanning optical microscope and its applications

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We describe the optimum design and construction of the near-field scanning optical microscope (NSOM) based on a short-probe tapping mode tuning-fork (TMTF) configuration and its applications in optoelectronic characterization and measurements. Unlike conventional optical shear-force mode NSOM, the tip-sample distance regulation is essentially realized by a non-optical and normal-force feedback control method in TMTF-NSOM. For that reason, TMTF-NSOM saves the troubles resulting from elaborate optical beam alignment and interference between the near-field optical signal and the force sensing optics in addition to providing all the advantages afforded by the tapping mode atomic force microscopy, including high spatial resolution, high sensitivity, and excellent stability. However, in some cases the friction or the massive load could be a critical issue in ordinary TMTF scheme. For example, when a long optical fiber with length longer than 80 cm was used, we could hardly sense any appreciable induced voltage difference between the two electrodes of the tuning fork under excitation. As a result, neither any significant feature of resonance response nor any noticeable change in the feedback signal as the tip approaches the sample surface could be observed. In order to overcome problems mentioned above, we devised the short-probe TMTF-NSOM, in which a cleaved short fiber probe attached to one tine of the tuning fork is used as the light collector/emitter as well as the force sensing element. Versatile applications of this novel short-probe TMTF-NSOM, such as near-field mode imaging of single-mode telecommunication optical fibers, silica based buried channel waveguides, and vertical-cavity surface-emitting lasers, optical characterization of InGaN/GaN multiquantum-well light-emitting diodes, and near-field imaging of evanescent wave interference, will be demonstrated in this paper.

5858-34, Poster Session

Elimination of 'ghost'-effect-related systematics in the x-ray optics metrology with long trace profiler

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The long trace profiler (LTP) is a basic metrology tool for highly accurate testing the figure of X-ray optics with slope variations on the order of one micro-radian rms. The LTP records the local slope profile of a surface by measuring the reflection angle of a laser probe beam as the beam is transported across the surface by an air bearing carriage. Beginning with the second generation LTP systems, a reference arm in addition to the probe arm is used to subtract the systematic errors related to laser pointing instability and carriage wiggling. The probe and the reference beams produce separate spatial patterns of interference fringes on corresponding position-sensitive detectors. The position of a pattern depends on reflection angle for the beam. Separation between the probe and reference patterns is a measure of the slope of the mirror surface at the point of measurement. The origin of the 'ghost' effect is the cross-contamination of the probe and reference signals one into another. As the 'ghost' signal overlaps with the primary signal, the computed centroid of the pattern changes depending on the relative position of the 'ghost' leading to the systematic perturbation in the measured slope trace of about 1-2 micro-radians. The 'ghost' effect is significantly increased for a cylindrical or a twisted mirror, because the interference feature from the probe arm moves not only tangentially along the corresponding detector array, but also in the sagittal direction, spilling onto the detector for the reference arm lying parallel to it. The main results of this work are a new improved LTP data acquisition technique, and special software developed to reduce this systematic effect. The idea is to separately measure the 'ghost' features in both arms and then subtract the 'ghost' intensities from the corresponding interference patterns. The procedure preserves the advantage of simultaneously measuring the probe and reference signals. A series of successive LTP intensity measurements with open and blocked beams are linearly combined with a specially developed program based on National Instruments LabVIEW software. The program constructs new probe and reference intensity files, which are then fitted with the usual LTP fitting procedure to find corrected slope values. The effectiveness of the proposed method for minimizing the LTP systematic error due to the 'ghost' effect is illustrated with LTP metrology of a variety of X-ray mirrors.
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5858-35, Poster Session

Airy-like internal reflection series applied in scatterometry and simulations of gratings

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Optical-scatterometry techniques became recently important tools for measuring critical dimensions of periodically patterned structures. Various theoretical models are applied to extract the geometrical and/or material parameters of those structures and to predict proper fabrication parameters for manufacturing optical filters such as grating monochromators, wire-grid polarizers, 'moth eye' antireflection surfaces, etc.

For the optical simulations we use the most common theoretical approach, the rigorous coupled wave analysis, which exists in various implementations. We show that the Airy-like internal reflection series is its stable implementation, capable to simulate the optical response of any type of laterally patterned structures. As proper examples we have chosen rectangular-relief gratings patterned on dielectric, semiconductor, and metallic surfaces and a sinusoidal-relief grating patterned on a dielectric surface.

Detailed numerical analyses including the convergence and time of computer simulations and fitting of the grating systems under investigation illustrate the powerful abilities of the spectroscopic-ellipsometry based scatterometry.

5858-36, Poster Session

A novel cavity control technique for the stabilization of a burst, pulsed laser

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An novel control technique used to get high optical frequency stability of a burst pulsed laser is described. To increase the frequency stability the pulsed laser is continuously seeded by a very stable CW laser. In order to tune the laser cavity length to the seeding laser optical frequency, the cavity, between the laser pulses, is used as a Fabry Perot interferometer

fed with the CW seeding laser. The interferometric signal is detected with a photodiode placed behind one of the cavity mirrors. A cavity mirror is mounted on a piezoceramic actuator for tuning the cavity length to the seeding laser optical frequency.

A proper patented algorithm performs the scanning of the laser cavity in order to find the best cavity transmission. Such cavity length is set before each laser pulse. With this approach the pulse repetition rate is not affected by any jitter caused by the control algorithm operation, as it happens for other similar techniques, thus allowing a precise synchronization of each laser pulse with an external trigger. The algorithm was also conceived to automatically compensate for any error introduced by the piezoceramic actuator hysteresis and non linearity.

The control algorithm also analyzes the laser pulse shape by using a proper hardware/software subsystem. By doing so the algorithm can compensate for any difference or drift occurring between the measured cavity length (the one present between the laser pulses) and the cavity length present during the laser pulse. In this way it is possible to prevent the generation of multimode laser pulses caused for instance by component aging.

5858-37, Poster Session

Comparison of methods for the determinaion of the apertur correction of interference microscopes

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For precision traceable measurements with interference microscopes it is neccessary to know the aperture correction factor. The source of the correction is the finite diameter of the illumination light source. If there is no further knowledge about it, the usual way is the calibration of the instrument with a reference standard. In this contribution a practical way is described to determine the aperture correction factor of an interference microscope by direct measuring the diameter of the illumination aperture. One way presented elsewhere is the projection of a line scale into the back focal plane of the objective and to observe it at the same time with the image of the aperture through the eye piece tube. In the second way a diffraction pattern of a line scale is directed into the microscope objective. In the back focal plane the set of diffraction orders acts a scale with known dimension. In the same way as before the scale of the diffraction orders can be observed through the eye piece tube together with the image of the aperture. So the diameter of the aperture can also be determined. Under the assumption of an accepted model the correction factor can be determined. Some considerations for the practical use and results are presented.

5858-38, Poster Session

Biological specimens analysis using dynamic speckle spectral bands

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Dynamic speckle or biospeckle is observed in biological samples illuminated by laser light. There are several methods for displays the speckle patterns activity using the local contrast analysis for monitoring capillary blood flow, the accumulation of differences between images to show the micro-circulation map of the human skin surface, the signal-to-noise ratio (SNR) to visualize the blood flow map of the human retina, the spatial and temporal speckle pattern for analysis atherosclerotic plaque and on time-dependent speckle in holographic optical coherence imaging applied to the study of tumor tissue health, etc. In these methods, the result is a single image that shows a certain measure of the total activity of the sample.

In this paper, we propose a method to analyze the biospeckle activity based in decomposition of images in temporary spectral bands that permits to obtain several measures with a better defined meaning thus adding to a better detailed characterization of the behavior of the samples. Butterworth filters are applied to the temporary evolution and different images are constructed showing the energy in each frequency band. Different degrees of activity of the sample in study presumably attributed to different origins are found.

The method is exemplified with images of bruising damage in fruits and biological activity in germinating corn seeds. It is found that the activity in the bruised region of an apple differs from the activity of healthy regions in a certain characteristic frequency range. The activity of the embryo can also be distinguished from that of the endosperm in corn seeds in germination process.

5858-39, Poster Session

A VDI-guideline for the calibration of interference microscopes - presentation and practical use

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In a committee of German VDI a guideline for the calibration of interference microscopes was established, which is now in the state of a draft. The steps of the calibration procedures including the calibration standards to be used are summarized. The steps include the determination of noise, flatness of reference plane, short wavelength cutoff, calibration of horizontal and vertical axes and the calculation of measurement uncertainty. The measurement results are condensed in a report, which may be - together with the guideline- the technical base for agreements of acceptance between suppliers and customers. To demonstrate the feasibility of the guideline, in the PTB the metrological behaviour of a commercial instrument was examined according to these procedures. The results show, that this guideline helps as well to determine some essential features of an interference microscope as to calibrate it basically in a traceable way.

5858-40, Poster Session

Investigation and evaluation of scatterometric CD metrology methods

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With decreasing critical dimensions (CD) on lithography masks, increasing demands on CD metrology techniques come along. Already today the results of the three standard methods for CD measurements currently used, atomic force microscopy (AFM), scanning electron microscopy (SEM), and optical microscopy, typically do not yield the same results. This is because of, e.g. incomplete knowledge of the material parameters, insufficient modelling or - especially in the case of optical microscopy - insufficient resolution. With decreasing CD's these systematic differences increase. The need on new cross-calibration strategies arises.

Non-imaging metrology methods like scatterometry as non destructive, non diffraction limited, fast optical methods offer access to the geometrical parameters of periodic structures like e.g. top and bottom CD, pitch, side-wall angle, line height, or roughness. Therefore these methods provide independently achieved additional information that can be used for cross-calibration.

At the PTB two scatterometers are in use (VIS \@ 633 nm and EUV \@ 13.5 nm). A third device (i.a. DUV \@ 193 nm) is under construction. It will offer a wide spectrum of measuring principles like scatterometry, ellipsometric and phasemodulation scatterometry, reflectometry, polarisation reflectometry, and using a continuous broadband light source spectroscopic ellipsometry and spectroscopic reflectometry.

For simulation and modelling of the intensity distribution of the diffraction pattern two programs based on the rigorous coupled-wave analysis (RCWA) method and a finite element method (FEM), respectively are used. The program features will be compared and their influence on the results will be illustrated.

A comparison of the simulations with the results achieved with the scatterometers on different types of lithography masks (Chrome on Glass, EUV-masks) will be presented as well.

5858-41, Poster Session

Analytical model of a double grating system with partial temporal and spatial coherence

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Grating pseudo images are formed in cascade grating systems and are useful in different fields and in many different applications, such as interferometry, optical encoding of position, etc. There are several processes for creating images of a grating by using only gratings as imaging elements, being the most known the Talbot effect. In other configurations one grating acts as an imaging element for another grating, such as the Lau effect where two identical gratings are illuminated with an extended monochromatic light source, and a pseudoimage of the first one is formed at infinity. In Generalized Grating Imaging, pseudoimages form, without the need for lenses, at finite distances of the gratings. One disadvantage that a grating pseudoimaging system presents for most applications is the fact that the contrast of self- and pseudo-images strongly depends on the distance between gratings. This makes the optical devices less tolerant to positioning and/or manufacturing. It has been shown that, for Talbot effect, the use of polychromatic light can eliminate the dependence of the contrast on the grating position. A similar result has been numerically demonstrated for some pseudoimages in a double

grating system with spatial and temporal partially coherent light. In this work we present an analytical model for Ronchi gratings that justifies and explains the numerical results previously obtained.

5858-42, Poster Session

Non-destructive optical system based on digital holographic microscope for quasi real-time characterisation of a micromechanical shunt switch

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A digital holographic microscope (DHM) is employed as non-invasive metrological tool for inspection and characterization of a micromechanical shunt switches in coplanar waveguide configuration (CPW) for microwave applications. Microelectromechanical switches have been recently considered as alternative key elements with respect to PIN diode switches for high frequency applications and as key components in future microwave and millimeter wave telecommunication systems. The switch is based on a bridge that can be actuated by using electrodes positioned laterally with respect to the central conductor of the CPW. By using this solution, the DC signal for the bridge actuation is separated by the RF signal. The DHM features, such as speed, contact-less and non-destructivity, have allowed a full characterization of an electrical actuated shunt switches. In particular, the out-of-plane deformation of the bridge due to the applied voltage has been investigated with high accuracy. In other words, applying an actuating voltage the bridge pulls down towards the dielectric plane and it is instrumental to characterize this actuation both to validate the theoretical approach used to model the devices and to increase their reliability. DHM inspection allows to investigate the shape of the bridge during the actuation, the total warpage due to the actuation, possible residual gap, possible hysteresis, and so on. These characterizations have been carried out both in static and in dynamic condition. In full paper the complete characterization will be reported together with an accurate description of the optical system employed for the investigation.

5858-43, Poster Session

Uncertainty analysis for phase measurement on PSM with a 193nm common-path shearing interferometer

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Scaling down the critical dimension (CD) also requires a reduction of systematic and stochastic errors in the measurement of phase shifts introduced by phase shift masks (PSM). Furthermore, in current mask design all degrees of freedom are used to satisfy the requirements and consequently different types like attenuated or alternate PSM are in use. A direct measurement of the introduced phase shift - the wave field propagating from the mask - is mandatory to further reduce the CD error budget. Although different interferometer set-ups might be used, a common path design enables a high repeatability of the measured phase values by being less sensitive to vibrations and air turbulence. Furthermore systematic errors due to different optical aberrations present in different arms of an interferometer are eliminated.

A lateral shearing interferometer was realised by adding two phase gratings and one amplitude grating to a microscope working in transmission. Thus a very stable tool for the measurement of phase shifting structures at lambda = 193 nm was obtained. The repeatability of the phase measurement is less than 2pi/1100.

To apply a simple method for the phase evaluation and to reduce the influence of the edges of phase shifting structures a totally sheared object wave was used. Moreover, this method provides a larger number of measured phase values compared to the case of differential phase contrast. To reduce the contribution of the visibility to the uncertainty budget the spatial degree of coherence was tailored to obtain a visibility V \› 0,8 even at large shear distances. The 5-phase algorithm was used to introduce the reference phase steps DELTAphij.

A model based description of the measurement was made. The uncertainty of the measured phase value of the introduced interferometer is |DELTAphi(max)| = 2pi/400 if an optimal adjustment of the system is achieved. This value can be reduced by a factor of 2 if the dependence of the phase shifting algorithm on the measured phase value is taken into account. A further reduction can be obtained if an intensity monitoring is implemented.

Measurements performed at different adjustment states are given to discuss e.g. the influence of the adjustment of the two phase gratings on the uncertainty budget. The contributions due to the strategy the phase value is estimated from the two- dimensional phase distribution given by the phase shifting algorithm and the influence of the layout of the object on the phase error are analysed too.

Although the results obtained - due to the prototype status - are not yet completely satisfactory, the described analysis proves the potential of the newly developed interferometer for further reduction of uncertainty and possible use as a reference phase measurement instrumentation.

5858-44, Poster Session

New imaging method using dynamic digital birefringence in nano particles and nano structure patterning calibration

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Calibration of the Nano particle agglomeration during production and transportation is the most important issue after an excellently functional nano product has been put into demand. So is calibration of nano structured patterns such as fibre gratings in sensor production. We use a paterned imaging and data analysis technology, MetriPol, to follow the naon- and micro-metroloic change.

MetriPol uses circular polarization state sweeping, analysing and dynmic data solving to digitally image and quantify minute quantity (best resolution ‹ 0.02 nm retardation) of optical anisotropy produced by light through a microscopic sample. It preserves the highest posibble resolution of a normal optical microsope while add normally unseable features and contrast which caused by any optical anisotropy.

In this paper, we report successful imaging and analysis result used to follow the agglomerate states change of nano particle such as anatze TiOx when the chemical structure changes between three oxide states: 0‹x‹2, x=2, 2‹x‹3. We will also show the result that no microscopic method can reach in the imaging and analysis of a laser patterned optical fibre gratings used in temperature, pressure and chemical sensing.

5858-45, Poster Session

Mueller polarimetry in conical diffraction for CD measurements in microelectronics

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Fast and efficient metrology tools are required for critical dimension (CD) control in microelectronics. Optical techniques proved to be a good choice for such task. Up to now spectroscopic ellipsometry (SE) is widely used to characterize 1D periodic structures in planar diffraction geometry, with grooves perpendicular to the incidence plane. Though SE data are very sensitive to some features, they are completely insensitive to others, e.g. groove asymmetry.

More extensive sets of experimental data can be obtained if the grating is measured at different azimuthal angles, i.e. in conical diffraction geometries. As the grooves are no longer perpendicular to the incidence plane, the Jones matrix of the sample is non-diagonal, and can be measured completely only by a generalized ellipsometer, or a Mueller polarimeter.

We used this approach with 1D gratings etched in photoresist layer on silicon wafer for nominal CDs down to 70 nm. The instrument was an novel Mueller polarimeter based on ferroelectric liquid crystals, and operated in the visible wavelength range. The measured spectra were fitted with a RCWA code in conical diffraction, with rectangular and trapezoidal profiles. This approach allowed us to reduce the parameter correlations observed with conventional SE both for asymmetrical grooves and for the very small CDs.

5858-46, Poster Session

Effect of the refraction index in the diameter estimation of thin metallic wires

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The most common technique for diameter measurement of thin metallic cylinders is optical diffractometry. It consists in illuminating the cylinder with a collimated monochromatic light beam, determining the diameter from the location of the minima of the far field diffraction pattern. Babinet principle is normally assumed, being the diffraction pattern of the cylinder equivalent to that of a strip whose width is equal to the cylinder diameter. Due to the three dimensional nature of the cylinder, this model is not valid for accurate measurements. It has been experimentally shown that, when compared to interferometry, Fraunhoffer model presents a systematic overestimation in the cylinder diameter. Rigorous models which assume that the wire presents an infinite conductance have been developed. However, the refraction index of the material has also appeared important for an accurate estimation since it produces a phase shift of the reflected wave by the wire surface, modifying the state of polarization of the incident light beam and, as a consequence, the location of the diffraction

minima. In this work we propose a model based on the Geometrical Theory of Diffraction that assumes both the three-dimensional nature and a finite conductance of the wire. Results for several materials are presented, showing that the overestimation of the wire diameter depends on the state of polarization and wavelength of the incident light beam, as well as the diameter and refraction index of the metallic wire.

5858-12, Session 3

Influence of the real-life structures in optical metrology using spectroscopic scatterometry analysis

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Today, scatterometry measurement has become mature for 1D-grating measurements. Nevertheless, certain aspects of this method of measurement are always under research studies. The measurements have been carried out on KLA-TENCOR ellispometer and on Nanometrics reflectometer in order to compare the two methods of measurement. The simulations have been done with MMFE (Modal Method of Fourier Expansion) software developed by LETI. The model structure chosen to describe line profile is a trapezoid. To control default characteristics and default repartition, one wafer was printed using electron beam lithography. The aim of this paper is the evaluation of the impact of defects in the grating on the spectroscopic signatures and its influence on extracted geometrical parameters by fitting the experimental curves. Different deviations to real-life structures have been studied and were described in two distinct parts. In the first part we focus on the influence of typical defects encountered in lithography processes such as bridging and partial destruction of lines and on the influence of CD distribution values inside the grating. In a second part we study the influence and the possibilities in detecting or measuring Line Edge Roughness (LER). All the results obtained have been compared with imaging standard tool: top down SEM measurement.

5858-13, Session 3

Comparative CD-SEM and scatterometry study of intra-wafer and intra-exposure field CD uniformity for process control of GC stack

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For the electrical performance of the MOSFET used in semiconductor logic or memory devices the gate contact (GC) line width (CD) is a key parameter that needs to be controlled accurately in the course of the manufacturing process flow. To meet the tighter specifications of future highly integrated devices it is mandatory to incorporate an accurate and repeatable CD measurement after every relevant patterning step during the processing of the GC-module. While CD-SEM represents the currently used standard method scatterometry comprises a potent alternative for GC CD control.

This work is aimed to provide a comprehensive comparison of both metrology methods for GC control. First, the CD uniformity across an exposure field is characterized for that purpose. A large number of chosen measurement sites allow a high resolution investigation of the characteristic exposure signature after the lithographic and the subsequent etch steps. Second, the characteristic wafer uniformity signatures of different wafers are also determined. It is shown that the scatterometry method can fully reconstruct the characteristic signatures seen from CD-SEM investigations. Even more, the observed signatures of the intra exposure field and of the wafer mappings are less noisy since scatterometry allows averaging over a large number of individual periodic structures due to the large spot size of the incident beam. Extensive measurements have been performed on all three patterning process steps in the GC module in order to determine how the imposed signature after lithography is propagated after the consecutive etching steps.

Finally, pilot run data are presented that show the performance of scatterometry for GC control under productive conditions.

5858-14, Session 3

Extending conventional scatterometry using generalized ellipsometry

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We investigated so-called cross polarization (or polarization conversion) effects for extending the capabilities of conventional spectral-ellipsometry based scatterometry. Therefore we developed a procedure how to use an automated rotating polarizer ellipsometer to determine the quotients between diagonal and off-diagonal elements of the Jones matrices for suitable samples. This generalized ellipsometry leads to six spectra instead of two, which can be used to extract more information about the geometry of diffraction gratings from an ellipsometric measurement.

We created spectral libraries by rigorous coupled wave analysis, which contain the elements of the Jones matrix for different grating geometries. These libraries allow an analysis of measured spectra as well as sensitivity studies and optimizations for different analyzer angles and grating orientations with respect to the plane of incidence (conical diffraction). Due to sidewall effects, which might cause polarization conversion, we expect an advantage for measurements of asymmetric and 2D periodic structures by employing conical diffraction.

5858-15, Session 3

Determination of the optical properties of thin absorbing layers with spectroscopic ellipsometry and interferometric microscopy

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Spectroscopic ellipsometry (SE) is a very sensitive method used for optical thin layer characterization. However additional information for metal layer thickness verification is very useful especially when metal or absorbing layer is very thin, extinction index in UV-IR range has nonzero values, refraction index is nonlinear and structure is multilayered.

In this paper method of the optical properties of thin layers in MOS structure determination is presented. Example structure is composed of Si substrate o, with continuous layer of thermally grown SiO_2 layer and with semitransparent Al gate electrodes. Al electrodes have thin Al_2O_3 layer on its top, and after annealing SiO_2 thickness under Al is expected to be a few nm thinner than outside the gate area. Thickness and refraction index of SiO_2 outside Al gate can be precisely determined with SE. Additional ellipsometric measurements, made on the whole structure allow determination of approximate thicknesses of SiO_2, Al and Al_2O_3 and n and k of Al. These values are only approximate because despite wide spectral range and multi angle measurements many parameters are determined simultaneously and due to parameter correlations there is no guarantee that found solution is unique.

Additional, important information about structure could be obtained from interferometric measurements. In this method, border of Al gate area create step which shifts interferometric pattern proportional to and optical path difference. This shift can photographed and be measured using simple image analysis system and optical path difference can be determined with accuracy in the range of 1nm. However; this shift contains information not only about metal layer thickness but about the whole structure within light penetration depth. The shift has to be accurately calculated from phase delay based on optical indexes and layer thicknesses found by SE. Comparing measured and calculated shifts it is possible to verify optical model created by SE and thus more accurate than with SE alone, determine Al thickness and its n and k values.

5858-16, Session 3

Stress and morphological stability of ultra-thin nickel silicide and nickel germanosilicide films probed by micro-Raman spectroscopy

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Due to its linewidth-independent low resistivity, low-temperature, one-step annealing and low silicon consumption, nickel monosilicide (NiSi) is one of the most promising candidates for contact to Silicon. The thickness of such silicide layers decreases as the dimensions of electronic devices are scaled down to sub-micrometer regions. Therefore, it is of great interest to study crystalline and vibrational properties of ultra-thin NiSi films with a microscopic characterization tool. In this study, we report morphological, vibrational, and electronic properties of ultra-thin NiSi and NiSiGe films, formed by sputtering of 5 and 10 nm pure Ni and NiPt(5%) on (001) Si, relaxed SiGe, and strained Si substrates. The morphological stability of the silicide films formed on these substrates shows no obvious difference in the case of pure Ni. However, in the case of NiPt(5%), electrical properties and morphological stability of the silicide films are significantly improved on relaxed SiGe when compared to other two substrates. This is due to the modification of the interfacial stress at the interfaces of silicide films and the substrates. Micro-Raman measurement has been carried out to investigate such interface stress states and thermal stability of ultrathin silicide films. Optical phonon peaks in the Raman spectra of NiSi and NiSiGe films are used to correlate the stress and morphological stability. The formation of Ge-rich NiSiGe phase and the segregation of Ge under different thermal annealing conditions can also be probed by micro-Raman spectroscopy. Such microscopic optical characterization leads to better understanding of the interface structure and crystalline properties of nickel based silicides and germanosilicides.

5858-17, Session 3

Polarimetry: measurements, errors analysis and applications

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There are two groups of polarimeter space- and time-division. In the first group the beam is split in four and the resulting beams are processed in parallel. The time-division polarimeter requires rotation stage for adjustment of the polarizable components.

In this letter the different polarimetric setups will be reviewed with a focus on measurements and errors analysis. The polarimeter was extensively used for linear and circular birefringence measurements and a lot of effort has been made to improve the accuracy and to find a setup with high flexibility.

The application of polarimeter will be reviewed with a detail analysis of the metrological application. It is described the polarimeter that we use for Stokes parameters calculation. The setup follows a classical approach for determination of all components of the Stokes vector by using a unique detector. Each optical component (quarter wave plate and linear polarizer) is mounted on a rotation stage that brings more freedom to control the measurement process and errors.

Two algorithms for the Stokes vector components calculation are used to consolidate the technique. The model presented here allows calculation of the polarizer azimuth that compensates the retardation error of the quarter wave plate. The setup is simple, stable and allows high precision calculation of the Stokes vector.

5858-18, Session 4

Optical coherence tomography with a Fizeau interferometer configuration

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Optical coherence tomography (OCT) is an optical imaging technique enabling the acquisition of 3D sub-surface information from turbid biological or engineering samples. Although a few OCT systems are now commercially available, mainly for ophthalmologic applications, the technique is still under development. This paper describes the advantages of a new configuration, developed in our laboratories, based on a fibre-optic Fizeau interferometer and balanced optical detection.

OCT uses the low-coherence properties of broadband optical sources to obtain localised structural information from a sample, with high spatial resolution. Interference fringes, corresponding to refractive index discontinuities within the sample, occur when the optical path difference between the sample and the reference arms is within the coherence length of the source. Most of the OCT configurations currently in use are based on a Michelson interferometer. However, this arrangement suffers from polarisation fading and thermal sensitivity of the fringes.

We report the investigation of a Fizeau interferometer-based OCT system. A secondary processing interferometer is necessary in this configuration, to compensate the optical path difference formed in the Fizeau interferometer between the end of the fibre and the sample. The Fizeau arrangement has the advantage of 'downlead insensitivity', which eliminates polarisation fading. An optical circulator is used in our system to route light efficiently from the source to the sample, and backscattered light from the sample and the fibre end propagates through to the Mach-Zehnder processing interferometer. The choice of a Mach-Zehnder processing interferometer, from which both antiphase outputs are available, facilitates the incorporation of balanced detection, which often results in a large improvement in the Signal-to-Noise ratio (SNR) compared with use of a single detector. Balanced detection comprises subtraction of the two antiphase interferometer outputs, implying that the signal amplitude is doubled and the noise is well reduced. We have carried out a theoretical comparison between equivalentMichelson and Fizeau interferometer OCT configurations, showing that a similar maximum SNR is expected for each.

Our experimental OCT system uses a broadband source centred at 1550 nm with a full-width-half-maximum of 40 nm, providing an axial resolution of 18 μm. The probe used to focus the light into the sample provides a transverse resolution of 30 μm. All components in the system are specified for 1550 nm to minimise losses. Calibrated refractive index oils have been used to characterise the SNR performance of the system using either single or balanced detection, and the results of this investigation will be presented. The system has been applied to structural imaging of samples including fibre composites and glass/liquid 'phantoms', and the images obtained have been compared with independent structural data obtained using a standard microscope.

5858-19, Session 4

Full-field optical coherence tomography

H. D. Ford, R. P. Tatam, Cranfield Univ. (United Kingdom)

Optical coherence tomography (OCT) is a medical imaging technique for probing the sub-surface structure of the epithelial and endothelial tissues of the body. It is also used in ophthalmology, since the high transparency of the internal media of the eye allows non-invasive imaging of the internal tissues.

In OCT, the biological sample replaces a mirror in one arm of a dual beam interferometer. A low coherence source is employed, a typical coherence length being between 3 and 30 microns. Interference fringes are seen only when the path lengths in the interferometer match to within the coherence length. The magnitude of the fringes is dependent upon the reflectivity of the sample at a particular depth, with high reflectivity corresponding to the refractive-index discontinuity across an interface between two tissue types. Thus, scanning the path-length of the interferometer reference beam generates high-resolution structural data as a function of depth below the sample surface.

A single depth scan provides one-dimensional (1D) data. To extend this to a 2D or 3D image requires information to be gathered from an array of positions across the sample surface. There are two approaches to this; the first is to scan the probe beam across the sample surface, typically using galvanometer-mounted mirrors, and to acquire a depth scan at each position. To date, this has been the most popular method, due to the high rate of data acquisition that can be achieved. However, in optical-fibre based systems, scanning must be carried out at the distal end of the probe fibre. While this is not usually a problem for laboratory measurements, such systems are often used endoscopically for in-vivo investigations and electrical power must be delivered to the endoscope tip to drive a miniaturised scanning system.

In this situation, an electrically passive probe is an attractive alternative. To eliminate the requirement for mechanical scanning, we have investigated the use of multiple optical fibres in a Fizeau interferometer arrangement, for probe beam delivery. Each of the many fibres addresses a separate Fizeau interferometer, formed between the fibre end and the sample, allowing acquisition of structural information across a plane parallel to the sample surface with a single depth scan. The depth scanning components are contained within a path-balancing interferometer external to the OCT endoscope probe, which now becomes completely passive.

Ideally, a 2D or 3D OCT image should be acquired within a few seconds, both to minimise patient discomfort and to avoid motion artefacts in the images. In the past, full-field techniques were less attractive than mechanical single-spot scanning, because the frame rates of CCD cameras were insufficient to achieve 3D imaging within this timescale. However, steady improvements in frame rate mean that parallel-processing techniques can now compete with scanning methods for acquisition speed, with the additional advantage of enabling passive probe configurations to be designed.

The technique has been demonstrated in our laboratory, and has been evaluated on non-biological samples, including glass/air and metal/air interfaces, and OCT images will be presented in which steps and grooves in the samples can be identified.

5858-20, Session 4

Optimisation of low-coherence speckle interferometry (LCSI) for charcterisation of multi-layered materials

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Techniques based on Low Coherence Interferometry (LCI), and in particular Optical Coherence Tomography (OCT), are well established for structural imaging based on depth-resolved interferometrical measurements. Electronic Speckle Pattern Interferometry (ESPI) is used for optical non-destructive testing based on interferometrical deformation measurement.

Low Coherence Speckle Interferometry (LCSI) combines the depth-resolved measurement from OCT and the high-accuracy deformation measurement from ESPI. Depth-resolved deformation measurements enable e.g. the characterisation of the behaviour of interfaces in transparent and semi-transparent multi-layered materials or structures. It can e.g. be used for measurements through packaging windows during quality controll in the MEMS production.

In this paper the optimisation of the interference signal is investigated. The contrast of the interference signal depends on the configuration of the optical setup and the optical properties of the material. Theoretical investigations and measurements for optimising the beam ratio, the coherence function and imaging parameters are presented.

By optimising the interference signal the probing depth of the technique can be extended. This is demonstrated for a semi-transparent polymer material.

Finally, measurements of the deformation of interfaces in multi-layered materials are presented.

5858-21, Session 5

Portable interference device for roughness measurement

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The present stage of development of surface-processing technologies and thin-film growing requires improving of the systems for surface roughness control to provide both precise accuracy and real-time performance. These requirements may be satisfied using the optical correlation measuring devices, which provide non-contact, fast-acting, and high-accurate surface roughness control. A portable device for surface roughness control is presented in this paper.

Technical solution is based on the polarization shearing interferometer. In a shearing interferometer, the object field interferes with itself, rather than with the reference field, thus making possible the measurements of arbitrarily shaped surfaces with the radius of curvature larger than 0.2 microns. This is especially important e.g. in the photochemical industry to monitor the quality of calender shafts, in the space industry to monitor the quality of mirrors fabricated by diamond micro-sharpening etc. Calender shafts and spherical mirrors under finishing of them by diamond micro-sharpening were controlled, and sensitivity on the rms height parameter down to 0,001 microns was achieved.

5858-22, Session 5

Sub-0.1μm track width measurement using a common path optical interferometer and artificial neural network.

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Measuring fine track widths with optical instruments has become increasingly difficult as the dimensions of the features of interest have become smaller than the traditional resolution limit. This has caused a move to non-optical methods such as SEM and AFM techniques, or novel optical methods combined with signal processing techniques to provide measurements of these samples. In this paper, we will describe an approach that combines a common path scanning optical interferometer with artificial neural networks (ANN), to perform track width measurements that are considered beyond the capability of optical systems.

Artificial neural networks have been used for many different applications; we have previously used them in a system to measure thermally induced strain in semiconductor devices [1]. In the present application, ANNs are trained using profiles of known samples obtain from the scanning interferometer. They are then tested using tracks, which have not previously been exposed to the networks, in order to confirm the generalised nature of the ANNs. This paper will discuss the impacts of various ANN configurations, and the processing of the input signal on the training of the network.

The optical system used to obtain the profiles is a common path scanning optical interferometer[2]. It makes use of a computer generated holographic component as the beam-splitter, thus allowing the two interfering beams to traverse similar path through the system. The resulting common path interferometer provides extremely repeatable measurements, with signal to noise ratio approaching that of the shot noise limit. The characteristics of the system will be described.

A number of samples have been used to test the system. These include a line width standard sample provided by the NPL, and several samples specifically designed for this project. The line width ranges from 3mm down to 40nm. Some of the tracks are isolated, and others are grouped as double and triple tracks. In order to fully characterise the ANNs, both pure phase structures (tracks etched on Si substrate) and amplitude tracks (chromium deposited on glass substrate) are available.

Preliminary results on these samples show that line width down to 60nm can be measured with a standard deviation of 4nm. This is obtained using a HeNe laser, and a 0.3NA objective. These and other results will be presented. The potential of the technique will also be discussed.

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5858-23, Session 5

Absolute distance measurment using femtosecond pulse lasers

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The task of absolute distance measurement aims to determine the separation length between two objects with a single operation of measurement. Absolute distance measurements with high precision over extended ranges are needed in many fields of science and engineering. Optical interferometry enables to determine distances by referring to the wavelength of light used. However, well-established homodyne and heterodyne phase-measuring interferometry principles are basically suited for monitoring relative distances, in a more familiar terminology, displacements. Thus the optical displacement measurements have limitations when applied for absolute distance measurements because of their incremental nature; they should keep track of the relative motion of one object continuously with respect to the other.

In this paper, technological possibilities of using recently-available femtosecond pulse lasers for advanced absolute distance measurements are investigated. Special emphasis is placed on the use of femtosecond lasers particularly for absolute-distance measurements with sub-micrometer accuracy over extensive ranges. This investigation reveals that femtosecond lasers are capable of providing a suitable means of nanometrology by implementing dispersive comb interferometry in combination with synthetic wavelength interferometry. Experimental results demonstrate that high-precision measurements with sub-micrometer resolutions are possible over a range of 2 meters.

5858-24, Session 5

Testing the new methods for small-angle rotation measurements

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We present one of the applications of the Optical Vortex Interferometer (OVI). OVI is based on the regular net of optical vortices, which are generated by the interference of three plane waves. Disturbing one of the interfering waves causes the change in the position of the vortex points in the vortex net. The measurement is based on the tracking the vortex position change. This method can be used to determine small-angle rotation. OVI distinguishes two axis of rotation and the corresponding two rotation angles can be measured with sub-second resolution. The linear vibrations of the element being measured are automatically subtracted. The single measurements provide hundreds of measurements points, so the statistical methods for data analysis and corrections can be effectively applied. Also, the local wavefront disruptions can be identified and exclude from data analysis. In the paper we present the experimental testing of the method. To get the precise rotation of the one of the interfering waves the optical wedge is putted into one of the interferometer arm. The analysis shows that the amplitude decreasing does not influence the measurement accuracy. From the vortex net shifting the rotation angle of one of the interfering waves is calculated and this rotation is also used to calculate the refraction angle of the applied optical wedge.

The rotation angle measurements can be performed for the micro objects as well as for the macro objects. The described system can be easily adopted for optical wedge testing, parallel glass plate testing, surface topography characterization (both in micro and macro scale).

5858-25, Session 6

Measurement advances for micro-refractive fabrication

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Micro-refractive lenses are an important example of components and subsystems that are being used increasingly in optical sensors, communications, data storage, and other diverse applications. These lenses have a continuous relief surface such that details of their dimensional shape, refractive index, and homogeneity all influence performance. Measurement capabilities for micro-refractives fall short of the most demanding current and future needs and are complicated by the need to fabricate non-spherical refractive surfaces. The micro-refractives used in optical data storage and single mode fiber coupling, for example, present some of the most demanding measurements. To control the fabrication process, the target measurement uncertainties are approximately 3 parts in 10-4 for radius and on the nanometer scale for form measurements. Carrying out metrology at this level, particularly for aspheric surfaces, is very challenging and especially so for micro-scale components. Surface profiles for specific applications are challenging to fabricate and particularly difficult to measure. Our research focuses on measurement advances for these components and new data analysis strategies to optimize the impact of measurement results.

Micro-interferometry is the most promising tool and can be used to measure radius of curvature, focal length, dimensional surface errors, and transmitted wavefront. Micro-interferometry was pioneered in the mid 1990's by Schwider's group in Germany [1, 2] and Hutley's group in the U.K. [3]. Interferometry on the micro-scale is challenging for several reasons, and the most demanding measurement uncertainties have yet to be demonstrated. Ray-trace simulations show that instrument biases in micro-interferometry depend strongly on the nature of the part under test. Consequently, calibration and assessment of uncertainty sources must be done with care. Common practice is to calibrate with a single high quality artifact for measurements of a range of different radii, and we see that this is only approximately valid. Figure measurement calibration, for example, will be improved if the radius of the calibration artifact closely matches the radii of the test lenses, but acquiring such a range of artifacts is not practical. We have demonstrated the application of a self-calibration procedure for figure measurement, called the random ball test [4, 5]. In this test, calibration with a perfect calibration artifact is simulated by measuring patches on the surface of sphere and averaging, which is valid because the error on the surface of sphere is zero on average. By using this test, a range of high quality micro ball bearings can be used to cover a range of radii. We have developed a similar calibration method for transmitted wavefront measurements.

Radius measurements on the micro-scale are also challenging. Radius measurements require the identification of an interferometric null position when the lens under test is at two positions - the confocal position and cat's eye positions. Aberrations in the interferometer and ray-trace errors introduce a bias in the apparent location of these two positions. The same simple ray-trace simulation can be used to explore the order of magnitude of these effects. Again errors in the measurement become significant in the micro-optic regime. Correcting for the biases introduced by wavefront aberration and ray-trace errors remains an unanswered question. We have, however, developed a matrix approach to correct for stage motion errors as the part is translated between the confocal and cat's eye positions [6].

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5858-26, Session 6

Investigation of thermal expansion homogeneity by optical interferometry

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Different measurement methods exist for the extraction of the coefficient of thermal expansion (CTE). Among them the observation of the sample length as a function of its temperature is the most direct way. The use of phase shifting interferometry in combination with computer-based analysis of interference phase maps drastically improved interferometrically length measurements. In addition to the observation of the length itself, a length topography L(x,y) of the sample can be extracted and investigated at varying temperatures. From these results an upper limit of CTE-homogeneity can be calculated.

In this contribution it is demonstrated how L(x,y) can be obtained from the interferometrical measurements at different shaped samples. It is shown in which way disturbing influences can be removed so that uncertainties of L(x,y) in the sub-nm range can be reached.

5858-27, Session 6

Characterization and engineering of ferroelectric microstructures by interferometric methods

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In the last years lithium niobate (LN) has become one of the most important optical materials in optoelectronics and nonlinear optics for its large electro-optics and nonlinear optical coefficients. Ferroelectric materials are widely used in electro-optic, acousto-optic, and nonlinear optical devices, such as light modulators, beam deflectors, optical frequency converters, or tunable sources of coherent light for spectroscopic applications. Manipulation of ferroelectric domains into gratings, matrices, or other shapes is possible.

Fabrication of new ordered microstructures in LN samples through domain engineering followed by differential etching has been developed recently for applications in the fields of optics and optoelectronics. These microstructures are also important in optical ridge waveguides, alignment structures, V-grooves, micro-tips and micro-cantilever beams. Moreover, engineering ferroelectric domains by an electrical poling technique represents a key process for the construction of a wide range of photonic devices. Therefore, a thorough understanding of material properties and of the poling process are crucial issues.

New imaging and characterization tools are needed to assure the final desired quality of such microstructures or to monitor the engineering processes. Results are reported on the application of digital holographic microscopy for the inspection and characterization of different microstructures fabricated in bulk lithium niobate. Furthermore the imaging and visualization of the domain growth and its subsequent morphological evolution, through the domain wall motion, is important to control in real-time and in-situ the domain pattern fabrication process.

Digital Holography provides full-field simultaneous information about the optical amplitude and phase deformation induced by domain reversal process during poling. Moreover, it is demonstrated that a holographic interferometric method allows evaluation of the crystal internal electric field.

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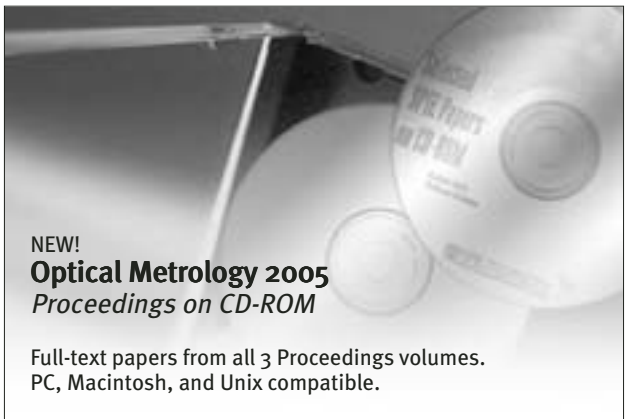

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