icOPEN 2023

International Conference on Optical and Photonic Engineering

27 Nov to 01 Dec 2023
Holiday Inn Singapore Atrium
www.icopen.org

PROGRAMME & ABSTRACT HANDBOOK

Organiser

Co-Organisers

icOPEN 2023 Secretariat

Supported by

Held in

CONTENT

WELCOME MESSAGE

On behalf of the organizing committee, we wish to extend a warm welcome to all of you to the 10th edition of the International Conference on Optical and Photonic Engineering (icOPEN), hosted by the Optics and Photonics Society of Singapore (OPSS).

Since 2008, OPSS has been promoting Optics and Photonics in Singapore through interaction between academia and industry, and actively participating in regional conferences and exhibitions. In recent years, OPSS has spearheaded the establishment of societies in various ASEAN countries, creating a dynamic community in the field.

The International Conference on Optical and Photonic Engineering (icOPEN) stands as a testament to our commitment to this field. Since its inception in 2011, icOPEN has steadily grown to become a prominent fixture in the Optical and Photonic Engineering calendar. Traditionally alternating between Singapore and China, it has evolved to include our ASEAN neighbours, with Thailand hosting the event in 2019.

In the face of challenges, such as the pandemic-induced hiatus, we've continued to adapt and innovate. The most recent edition of icOPEN was an online event organized in Nanjing in 2022. Now, we are delighted to announce the return of the physical conference in Singapore in 2023. This is an exciting opportunity for colleagues from around the world to not only showcase their cutting-edge research and exchange ideas but also to rekindle old friendships and forge new connections in a nurturing environment.

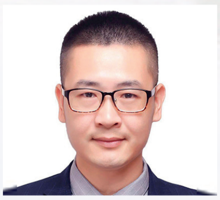
Together, we will explore the frontiers of Optical and Photonic Engineering, foster collaboration, and strengthen the bonds of our global community. Get ready for 3 days of inspiration, innovation, and camaraderie.

Welcome to Singapore and the icOPEN2023. Hope you have a fruitful and successful event.

Conference General Chair

Anand ASUNDI
d'Optron Pte Ltd

Co-Chairs



Fang CHENG
*Advanced Remanufacturing and Technology Centre (ARTC), A*STAR*

Cuong DANG
Nanyang Technological University

Aaron DANNER
National University of Singapore

Kemao QIAN
Nanyang Technological University

Haixia WANG
Zhejiang University of Technology

COMMITTEE

LOCAL ORGANISING COMMITTEE

GENERAL CHAIR

Anand ASUNDI
d'Optron Pte Ltd

CO-CHAIRS

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*Advanced Remanufacturing and Technology Centre (ARTC), A*STAR*

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Zhejiang University of Technology

Aaron DANNER
National University of Singapore

Kemao QIAN
Nanyang Technological University

SCIENTIFIC COMMITTEE

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Shijie FENG
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Yu FU
Shenzhen University

Banglei GUAN
National University of Defense Technology

Jing HAN
Nanjing University of Science and Technology

Xianfu HUANG
Institute of Mechanics, Chinese Academy of Sciences

Zhenyu JIANG
South China University of Technology

Xide LI
Tsinghua University

Haibo LIU
National University of Defense Technology

Mengxiong LIU
Peking University

Zhanwei LIU
Beijing Institute of Technology

Wenlong LU
Huazhong University of Science and Technology

Qinwei MA
Beijing Institute of Technology

Xiang PENG
Shenzhen University and Shenzhen Anhua Optoelectronics Technology Co., Ltd

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Guohai SITU
Shanghai Institute of Optics and Fine Mechanics

Jiasong SUN
Nanjing University of Science and Technology

Haixia WANG
Zhejiang University of Technology

Houxiao WANG
Shandong University

Xingzhan WEI
Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences

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Ningbo University

Huimin XIE
Tsinghua University

Jing XU
Tsinghua University

Yingjie YU
Shanghai University

Hongye ZHANG
Beijing Forestry University

Qican ZHANG
Sichuan University

Xiangchao ZHANG
Fudan University

Yilong ZHANG
Zhejiang University of Technology

Zibang ZHANG
Jinan University

Zonghua ZHANG
Hebei University of Technology

Jianlin ZHAO
Northwestern Polytechnical University

Dongliang ZHENG
Nanjing University of Science and Technology

Min ZHONG
Chengdu University of Information Technology

Jiangguo ZHU
Jiangsu University

Chao ZUO
Nanjing University of Science and Technology

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TU Dresden

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Advanced Remanufacturing and Technology Center

Joseph LIFTON
Advanced Remanufacturing and Technology Center

JAPAN

Motoharu FUJIGAKI
University of Fukui

Qinghua WANG
National Institute of Advanced Industrial Science and Technology

Satoru YONEYAMA
Aoyama Gakuin University

UNITED STATES

Chunlei GUO
University of Rochester

Lei HUANG
Brookhaven National Laboratory

Song ZHANG
Purdue University

SESSION ORGANISER DETAILS

SPECIAL SESSIONS

SS1: 2D, 3D and Volumetric Digital Image Correlation and Their Applications
Session Organiser:
Zhenyu JIANG, *South China University of Technology*

SS2: 3D Shape Measurement Based On Fringe Projection
Session Organiser:
Dongliang ZHENG, *Nanjing University of Science and Technology*

SS3: Advances in Digital Holography Techniques
Session Organiser:
Jianglei DI, *Guandong University of Technology*

SS4: Advances in Moiré Method and Its Applications
Session Organisers:
Hongye ZHANG, *Beijing Forestry University*
Xianfu HUANG, *Institute of Mechanics, Chinese Academy of Sciences*

SS7: High-accuracy Optical Deformation Measurement of Large Engineering Structures
Session Organisers:
Xinxing SHAO, *Southeast University Qinwei MA, Beijing Institute of Technology*
Banglei GUAN, *National University of Defense Technology*
Qinwei MA, *Beijing Institute of Technology*

SS8:High-precision Optical Measurement
Session Organisers:
Jing XU, *Tsinghua University*
Xiangchao, ZHANG, *Fudan University*
Wenlong LU, *Huazhong University of Science and Technology*

SS9: Imaging Through Scattering Media and Non-line-of-sight Imaging
Session Organiser:
Jing HAN, *Nanjing University of Sciences and Technology*

SS10: Industrial Optical Inspection and Non-destructive Testing (NDT)
Session Organisers:
Andrew Alexander MALCOLM, *Advanced Remanufacturing and Technology Center Joseph LIFTON, Advanced Remanufacturing and Technology Center*

SS12: Micro/Nano-Mechanical Measurement and Characterization of Optical/Spectral Methods
Session Organisers:
Mengxiong LIU, *Peking University*
Haimei XIE, *Tianjin University*
Xide LI, *Tsinghua University*

SS13: Optical Dynamic Measurement
Session Organisers:
Yu FU, *Shenzhen University*

SS14: Optical Measurement and Instrumentation
Session Organiser:
Yingjie YU, *Shanghai University*

SS15: Quantitative Phase Imaging
Session Organiser:
Chao ZUO, *Nanjing University of Science and Technology*

SS16: Single-pixel Imaging and Optical Encoding
Session Organisers:
Wen CHEN, *The Hong Kong Polytechnic University*
Zibang ZHANG, *Jinan University*

SS17: Infrared Thermography and Structural Health Monitoring and Evaluation
Session Organisers:
Jianguo ZHU, *Jiangsu University*
Dan WU, *Ningbo University*

SESSION ORGANISER DETAILS

SS18: X-ray Optics and Metrology
Session Organiser:
Lei HUANG, *Brookhaven National Laboratory*

SS19: Optical Engineering in Industry
Session Organisers:
Anand ASUNDI, *d'Optron Pte Ltd*
Xiang PENG, *Shenzhen University and Shenzhen Anhua Optoelectronics Technology Co., Ltd*

PLENARY SPEAKERS PROFILE

Peter de GROOT

Zygo Corporation, Middlefield, CT, United States

BIOGRAPHY

Peter de Groot, Chief Scientist at Zygo Corporation, is fascinated by interference fringes and their practical use for measuring things. He began his optics career as a teenager, grinding and polishing the mirror for a 100-mm reflecting telescope. Educated first in the liberal arts and then in experimental Physics at the Universities of Grenoble, Maine, and Connecticut, he enjoys discovering the underlying principles and hidden links behind creative work in science and engineering. His research has led to 140 US patents as well as over 210 technical papers, tutorials, and book chapters. He is a Fellow of SPIE, Optica, the Institute of Physics, and the International Academy of Engineering and Technology. An experienced teacher and lecturer, he is a short-course instructor and honorary professor. Dr. de Groot is also the 2023 Vice President of SPIE, the International Society for Optics and Photonics.

Xiaoyuan HE

Southeast University, China

BIOGRAPHY

Xiaoyuan He received his BS degree from the Department of Applied Mechanics at Nanjing University of Science and Technology, China, in 1982 and PhD from the Institute of Mechanics Southwest Jiaotong University, Chengdu, China, in 1994. Currently, he is a professor in the School of Civil Engineering at Southeast University. Since 1985, he has been engaged in photomechanics research and has been to many universities in the United States, Canada, Singapore and Hong Kong for visits and cooperative research. He has been invited to give academic reports in dozens of universities such as Purdue University, Auckland University, National University of Singapore, Hong Kong University of Science and Technology, Tsinghua University, University of Science and Technology of China, Northwestern Polytechnical University, etc. He has guided more than 80 domestic visiting scholars, postdocs, doctoral and master students in solid mechanics. He has presided over nearly 20 national scientific research projects, including “National Major scientific Research Instrument Development Project”, “National Natural Science Foundation Key Project” and “National Science and Technology Support Plan”. He has published more than 300 papers (including more than 200 papers indexed by SCI/EI) in the field of photomechanics and their applications, and has won more than 10 national invention patents.

Pascal PICART

Le Mans Université, France

BIOGRAPHY

Pascal Picart is a Professor at Le Mans Université, France. He graduated from the École Supérieure d’Optique in 1992 and received his PhD in physics from the University of Paris XI, Orsay, France, in 1995. He joined Le Mans University in 1996. He is the author of 110 journal papers, 24 invited talks, 162 proceedings in international & national conferences, 7 book chapters, coordinated 4 books and co-founded one start-up. His research topics are connected with coherent imaging based on digital holography and its various applications to acoustics, mechanics and fluid mechanics. Pascal Picart is member of the Optical Society of America (OSA), SPIE, Société Française d’Optique (SFO), European Optical society (EOS), Club EEA, Institute of Electrical and Electronics Engineers (IEEE).

Rachel Pei Chin WON

Nature Photonics, United Kingdom

BIOGRAPHY

Rachel Won is an International Editor of Nature Photonics. She joined the journal in June 2006 as one of four Founding Editors. Before that, Rachel worked for Aston University’s Business Partnership Unit in Birmingham, UK, as a Medici Fellow, commercializing the research output of the university, particularly that of photonics research. She obtained her PhD in microwave photonics and nonlinear optics as a member of Aston’s Photonics Research Group. She worked for Philips Optical Storage in Singapore as an Optics Engineer after completing her Master’s degree study in Nanyang Technological University of Singapore doing research in optical fibre sensing. She holds a Bachelor’s degree from the National University of Malaysia. She is a Fellow of the Optical Society of America (OSA) and the International Society of Optics and Photonics (SPIE).

SCIENTIFIC COMMUNICATION

SECRETARIAT AND SPEAKERS' PREVIEW ROOMS

Level 3, Boardroom, Holiday Inn Atrium

Opening Hours

28 November 2023, Tuesday	07:30 – 20:00 hours
29 November 2023, Wednesday	07:30 – 20:00 hours
30 November 2023, Thursday	07:30 – 17:00 hours

PLENARY, KEYNOTE & INVITED SPEAKERS GUIDELINE

- Please collect your Conference Badge and Pack at the Speakers' Desk.
- Please be at your presentation room during the break to test your computers with the hotel AV systems for compatibility.
- All PowerPoint presentations or videos must be in the 16:9 ratio format
- Speakers should report to the room of their presentation at least **10 minutes** before the start of the session to meet the session chairpersons.
- Speakers are required to adhere strictly to the following allocated presentation time allowance.

Session	Duration of Presentation
Plenary	45 Minutes (including Q&A)
Invited & Keynote	20 Minutes (including Q&A)

SESSION CHAIRS

- Bios of the presenting speakers in your session will be sent to the respective rooms before the session starts.
- Be at the presentation venue of your session at least 10 minutes before the session starting time. The room manager will introduce the presenting speakers to you.

STUDENT PRESENTATION AWARD (JUDGES)

- Scoring sheets will be sent to the respective rooms before the session starts.
- Report to Atrium Ballroom, Level 4 at least 10 minutes before the start of the session.

ORAL PRESENTER GUIDELINE

- Please proceed to the Registration' Counter to collect your Conference Badge & Pack.
- Please be at your presentation room during the breaktime for your computers to test the AV systems on your computer.
- All PowerPoint presentations or videos must be in the 16:9 ratio format.
- Presenters should report to the room of their presentation at least 10 minutes before the start of the session to meet the session chairpersons.
- Presenters are required to strictly adhere to the following allocated presentation time allowance

Session	Duration of Presentation
Normal Speaker	15 Minutes (including Q&A)

SCIENTIFIC COMMUNICATION

POSTER PRESENTER GUIDELINE

- Please proceed to the Registration' Counter to collect your Conference Badge & Pack.
- Mounting item will be provided at the Changi/Kallang Ballroom, Poster/Exhibition Area, Level 4.
- You are to print the poster in portrait format and the poster size is 0.9m (width) x 1.5m (height)
- Please standby at poster area during the lunchtime for any Q&A.
- Presenters are required to strictly adhere to the following allocated set-up and teardown time.

AGENDA	DATE
Set-up Date/Time	Monday, 27 November 2023, from 1600 – 1900 hours
	Tuesday, 28 November 2023, from 0800 - 0900 hours
Duration of Display	Tuesday – Wednesday, 28 - 29 November 2023, 0900 – 1700 hours
	Thursday, 30 November 2023, from 0900 – 1600 hours
Teardown Time	Thursday, 30 November 2023, 1600 – 1800 hours
Presenter standby Poster	Wednesday, 29 November 2023, 1230 - 1330 Hours (Poster section at the Exhibition Area)

THE FOLLOWING EQUIPMENT WILL BE PROVIDED FOR PRESENTATION

- Microphone, laser pointer & presenter clicker, video cable (HDMI) and projector
- Please bring your own laptop with the power adaptor and connecting video adaptor

CONFERENCE INFORMATION

MAIN CONFERENCE VENUE

Holiday Inn Singapore Atrium, Level 4
317 Outram Road, Singapore 169075

WIFI

High-speed high-density dedicated Conference WiFi is available throughout the Hotel.
INTERNET SSID : meet@holidayinn
Password : Not Needed

REGISTRATION AND INFORMATION DESKS

Registration will be available at Level 4, Changi Foyer, Holiday Inn Atrium, during the following hours:

27 November 2023, Monday	14:00 – 18:00 hours
28 November 2023, Tuesday	08:00 – 16:00 hours
29 November 2023, Wednesday	08:00 – 15:00 hours
30 November 2023, Thursday	08:00 – 10:00 hours

ON-SITE REGISTRATION FEE (PER PERSON, FULL CONFERENCE PASS)	CASH	CREDIT CARD
Full Delegation (Member: OPSS, CSOE, OSJ)	SGD 950.00	SGD 997.50
Full Delegation (Non-Member)	SGD 1,050.00	SGD 1,102.50
Student	SGD 650.00	SGD 682.50
Delegates (not submitting any abstract/paper)	SGD 650.00	SGD 682.50

NAME BADGE

Name badge is to be worn at all times for identification purposes and for admission to all scientific sessions, lunch, poster and exhibition area. Name badge is not transferable. The organiser reserves the right to request for proof of identification.
Should you lose your name badge. Please proceed to the Registration Desk at Level 4, for a replacement. Each replacement badge costs SGD 100.00.
The Organising Committee and Conference Secretariat are not liable for personal accidents, losses, or damage of private properties of registered delegates during the Conference. Delegates should make their own arrangement with regards to personal insurance

EVENTS AT THE CONFERENCE

Please join us for the following events:

WELCOME RECEPTION

Venue	:	Sentosa Room, Level 3, Holiday Inn Singapore Atrium
Day/ Date/ Time	:	Monday, 27 November 2023, 17:00 – 19:00 hours
Food & Beverage	:	Soft Drinks and Snacks will be provided

CONFERENCE DINNER @ TIEN COURT RESTAURANT

Venue	:	Tien Court Restaurant, Level 2F, Copthorne King's Hotel, 403 Havelock Road, Singapore 169632
Day/ Date/ Time	:	Wednesday, 29 November 2023, 19:00 - 21:30 hours
Dress Code	:	Smart Casual
Ticket	:	Ticket to be collected at the **Registration Counter** upon registration Only fully paid "Full Delegation (Members / Non-Members)" registrants are entitled for the conference dinner.
Price	:	SGD150 (for additional seat)
Meeting Point	:	Hotel Main Lobby, Level 1 @18.00 hours, @18.15 hours

CONFERENCE INFORMATION

LANGUAGE
The official language of the conference is English. There will be no simultaneous interpretation.

MOBILE PHONES
All mobile phones are to be switched off or in silent mode when entering the room and during all sessions

TEA & LUNCH BREAKS
Please refer to the programme for the timing.

SMOKING
Smoking is strictly prohibited within the conference venue. The organizer and the hotel staff reserved the right to request that you leave the conference venue. Check with the organizer or hotel staff for the designated smoking area.

INSURANCE
The Organisers cannot accept any responsibility for damage or loss of personal property during the Conference. All participants must purchase travel insurance covering medical bills and personal belongings.

PHOTOGRAPHY & RECORDING
Please note that there will be general photo-taking and recording during the Conference event programme, which may be used for publicity and public education by the society and the conference organiser.

DISCLAIMER
While every effort will be made to ensure that all aspects of the conference mentioned in this Programme Handbook will take place as scheduled, the Organising Committee reserves the right to make last-minute changes should the need arise.
Please note that by attending the conference, the Organising Committee and its subsidiaries, employees, agents and personnel who are acting on behalf of OPSS: reserve the right to use any image, voice or video taken during the conference, as a whole or part, for any future events.
You have the right to revoke this authorization by doing so in writing and submit your revocation to us. Any revocation submitted after the release of any information will not apply.

PROGRAMME OVERVIEW

Monday, 27 November	Tuesday, 28 November	Wednesday, 29 November	Thursday, 30 November	Friday, 01 December
	Registration (Level 4, Main Foyer) 0800 - 1600	**Registration** (Level 4, Main Foyer) 0800 - 1500	**Registration** (Level 4, Main Foyer) 0800 - 1000	**Site visit to d'Optron Pte Ltd and The Photonics Institute, Nanyang Technological University** 0930 - 1430 **Visit to d'Optron Pte Ltd** 8 Cleantech Loop, Block E #06-72 Cleantech 3 Singapore 637145 (No transport is provided) **Contributions of Holography** **Dr Peter De GROOT** *Zygo Corporation, United States* **Tour of d'Optron Pte Ltd** Coach Departs for Nanyang Technological University Lunch at NTU Canteen (Free and Easy and on Pax Account) **Tour of The Photonics Institute, Nanyang Technological University**
	Exhibition 0900 - 1700		**Exhibition** 0900 - 1600	
	Opening Ceremony and Plenary 0900 - 1050	**Plenary** 0900 - 1030	**Breakout 1** **SS12** 0900 - 1030	
			Breakout 2 **SS9** 0900 - 1030	
			Breakout 3 **GT12** 0900 - 1030	
	AM Break 1050 - 1105	**AM Break** 1030 - 1045		
	Keynotes 1105 - 1205	**Keynotes** 1045 - 1145	**Breakout 1** **SS8** 1045 - 1215	
			Breakout 2 **GT2, GT3** 1045 - 1215	
			Breakout 3 **SS1, GT10, GT15** 1045 - 1215	
Registration (Level 4, Main Foyer) 1400 – 1800 **SPIE Meeting** (Exclusively for students only) Sembawang Room, Level 3 1600 – 1800 **Welcome Reception** Sentosa Room, Level 3 1700 - 1900	**Lunch /** **Poster on Display** 1205 - 1330	**Lunch / Poster Session** (Presenter to Standby Poster) 1145 - 1330	**Lunch /** **Poster on Display** 1205 - 1330	
	Breakout 1 **Student Competition** 1330 - 1530	**Breakout 1** **SS14** 1330 - 1530	**Breakout 1** **SS7** 1330 - 1530	
	Breakout 2 **SS3** 1330 - 1530	**Breakout 2** **SS15** 1330 - 1530	**Breakout 2** **SS16** 1330 - 1530	
	Breakout 3 **SS10** 1330 - 1530	**Breakout 3** **SS18** 1330 - 1530	**Breakout 3** **GT12** 1330 - 1530	
		PM Break 1530 - 1545		
	Breakout 1 **Student Competition** 1545 - 1745	**Breakout 1** **SS2** 1545 - 1745	**Breakout 1** **SS13** 1545 - 1745	
	Breakout 2 **GT9,11 NDT and Others** 1545 - 1745	**Breakout 2** **GT13** 1545 - 1745	**Breakout 2** **SS16, GT1** 1545 - 1745	
	Breakout 3 **SS19, GT16** 1545 - 1745	**Breakout 3** **GT6** 1545 - 1745	**Breakout 3** **SS4, SS17** 1545 - 1745	
		Conference Dinner (Tien Court, Copthorne King's Hotel) *Meeting Point: Holiday Inn Atrium Main Lobby, Level 1 @ 18:00 hours, @ 18:15 hours*		

(Seletar 3, Level 3) (Seletar 2, Level 3) (Atrium Ballroom, Level 4) (Changi Ballrooms, Level 4)

SCIENTIFIC PROGRAMME

DAY 0: Monday, 27 November 2023

TIME	PROGRAMME
1400 - 1800	**Registration (Level 4, Main Foyer)**
1600 - 1800	**SPIE Meeting** (Sembawang Room, Level 3) (for students only) **Adventures in Optical Metrology** Dr Peter De GROOT *SPIE, Vice President*
1700 - 1900	**Welcome Reception (Sentosa Room, Level 3)** All are welcome!

DAY 1: Tuesday, 28 November 2023

TIME	PROGRAMME
0800 - 1600	**Registration (Level 4, Main Foyer)**
0900 - 1700	**Exhibition (Changi Ballrooms, Level 4)**
0900 - 0910	**Opening Ceremony (Atrium Ballroom, Level 4)**
0910 - 0955	**Plenary 1 (Atrium Ballroom, Level 4)** Session Chair: Fang CHENG **Testing optics with interferometry and tunable-wavelength lasers** Dr Peter De GROOT *Zygo Corporation, United States*
0955 - 1040	**Plenary 2 (Atrium Ballroom, Level 4)** Session Chair: Fang CHENG **Digital holographic metrology for imaging acoustics & vibrations** Prof Pascal PICART *Le Mans Université, France*
1040 - 1050	**Group Photo (Atrium Ballroom, Level 4)**
1050 - 1105	**AM Break (Changi Ballrooms, Level 4)**
1105 - 1125	**Keynote 1 (Atrium Ballroom, Level 4)** Session Chair: Cuong DANG **Specular surface shape measurement with collimated phase measuring deflectometry** Dr Lei Huang *Brookhaven National Laboratory, United States*
1125 - 1145	**Keynote 2 (Atrium Ballroom, Level 4)** Session Chair: Cuong DANG **The slope deflectometry system development for three dimensional profile measurement** Dr Fugui YANG *Institute of High Energy Physics, China*
1145 - 1205	**Keynote 3 (Atrium Ballroom, Level 4)** Session Chair: Cuong DANG **Sub-10 nm focusing of hard X-ray free-electron laser for reaching 10^22 W/cm^2 intensity** Prof Jumpei YAMADA *Department of Precision Engineering, Osaka University, Japan*
1205 - 1330	**Lunch/Posters on Display** **Exhibition Area (Changi Ballrooms, Level 4)**

SCIENTIFIC PROGRAMME

DAY 1: Tuesday, 28 November 2023

TIME	PROGRAMME				
Special Session (1330 - 1530)	**Breakout 1** (Atrium Ballroom, Level 4)	**Breakout 2** (Seletar 2, Level 3)		**Breakout 3** (Seletar 3, Level 3)	
	Student Competition *Session Chair: Shijie FENG*	**SS3:** Advances in digital holography techniques *Session Chair: Peng GAO*		**SS10:** Industrial optical inspection and non-destructive testing (NDT) *Session Chairs: Joseph LIFTON, Tong LIU*	
1330 - 1345	**15485:** High robust spatio-temporal wavefront prediction in adaptive optics via a mixed graph neural network **Ju TANG** *Northwestern Polytechnical University, China*	**1330-1350**	**15669:** Digital holographic reconstruction and generation with unpaired and dual-distance learning models **Zhenbo REN** *Northwestern Polytechnical University, China*	**1330-1350**	**15477:** Exploitation of Industrial X-ray Computed Tomography for Surface Metrology of Metallic Additively Manufactured Parts **Shan LOU** *Future Metrology Hub, University of Huddersfield, United Kingdom*
1345 - 1400	**15472:** Sub-Aperture Stitching Interferometry With Dual Quaternion For X-ray Mirrors **Shuai ZHANG** *University of Chinese Academy of Sciences, China*	**1350-1405**	**15498:** Engineering Axial Resolution Realtime And Post-Recording of Incoherent Holograms Using Hybridization Techniques **Shivasubramanian GOPINATH** *University of Tartu, Estonia*	**1350-1410**	**15500:** Automated Visual Inspection System For Visible Particulates In Injections **Shaowei FU** *Applied Materials South East Asia Pte. Ltd, Singapore*
1400 - 1415	**15511:** Image-based wavefront sensing and correction for atmospheric turbulence by using deep reinforcement learning **Mengmeng ZHANG** *Northwestern Polytechnical University, China*	**1405-1420**	**15529:** Surface Plasmon Resonance Holographic Microscopic Imaging Technology and Application Research **Jiazhen DOU** *Guangdong University of Technology, China*	**1410-1425**	**15638:** Transformer-Based Smart Inspection For Agricultural Products Via X-Ray Images **Chaoyu DONG** *Nanyang Technological University, Singapore*
1415 - 1430	**15497:** Parallel synthetic aperture transport-of-intensity diffraction tomography with annular illumination **Habib ULLAH** *Nanjing University of Science and Technology, China*	**1420-1435**	**15532:** High-speed 3D particle tracking using neuromorphic digital holography **Ge ZHOU** *Shanghai University, China*	**1425-1440**	**15481:** An initial study on using X-ray computed tomography to measure the surface roughness of additively manufactured metal lattices **Ronnie SSEBAGGALA** *University of Huddersfield / Advanced Remanufacturing, United Kingdom*
1430 - 1445	**15502:** Some recent advances in mirror-assisted multi-view digital image correlation **Kaiyu ZHU** *Beihang University, China*	**1435-1450**	**15574:** Digital Holography with Deep Learning for Algae Identification and Classification **Chinnapat RUTTANASIRAWIT** *King Mongkut's Institute of Technology Ladkrabang, Thailand*	**1440-1455**	**15650:** Use of X-Ray Computed Tomography (CT) of weld spots defects **Marcus NG** *Singapore Institute of Manufacturing Technology, Singapore*
1445 - 1500	**15514:** Heat haze neutralization on high-temperature digital image correlation measurements via deep learning **Yanzhao LIU** *Beihang University, China*	**1450-1505**	**15605:** Real-time 3D scenes acquisition method for light field 3D display **Qionghua WANG** *Beihang University, China*	**1455 -1510**	**15544:** Three-dimensional height measurement with an improved 3D camera **Hon Luen SECK** *Singapore Institute of Manufacturing Technology, Singapore*
1500 - 1515	**15531:** Validating The Efficacy of Deformation Distribution Measurement In CFRP Laminates During Three-Point Bending Using The Sampling Moiré Method **Tong DING** *Beihang University, China*			**1510-1525**	**15513:** Development of a vision system for cast mould defect inspection under extreme high temperature **Weili WANG** *Advanced Remanufacturing & Technology Centre (ARTC), Singapore*
1515 - 1530	**15573:** Deep learning-enabled structured light system for single-shot absolute 3D shape measurement **Yixuan LI** *Nanjing University of Science and Technology, China*				

SCIENTIFIC PROGRAMME

DAY 1: Tuesday, 28 November 2023

TIME	PROGRAMME				
1530 - 1545	**PM Break** **Exhibition Area (Changi Ballrooms, Level 4)**				
(1545 - 1745)	**Breakout 1** (Atrium Ballroom, Level 4)	**Breakout 2** (Seletar 2, Level 3)		**Breakout 3** (Seletar 3, Level 3)	
	Student Competition *Session Chair: Shijie FENG*	**GT9,11 NDT and others** *Session Chair: Chenxing WANG*		**SS19:** Optical Engineering in Industry *Session Chair: QiongHua WANG* **GT16:** Other Related Topics *Session Chair: QiongHua WANG*	
1545 - 1600	**15533:** The application of the moiré method to defect detection and strain imaging in Si single crystals **Qingcui HUANG** *Beihang University, China*	1545-1600	**15535:** Improved Video Motion Magnification Method Assisted by Digital Image Correlation **Tong DING** *Beihang University, China*	1545-1605	**15480:** All-In-One Microscope For 3D Inspection And Testing **Jingzhu HONG** *d'Optron Pte Ltd, Singapore*
1600 - 1615	**15534:** Development Of Light-induced Detection Method For Viruses With Plasmonic Nano-bowl Substrate **Masatoshi KANODA** *Osaka Metropolitan University, Japan*	1600-1615	**15538:** X-Ray computed tomography based high-accuracy analysis for the compressive properties of thin shell lattice structures: effect of geometric defects **Lei ZHANG** *Shanghai Jiao Tong University, China*	1605-1625	**15520:** An introduction of resin SRG wave guides in AR glasses **Weizheng Huang** *Meta-Bounds, China*
1615 - 1630	**15507:** Uniform LIPSS on Copper Created Using Zeroth-Order Femtosecond Bessel Beam For SERS-based Applications **Dipanjan BANERJEE** *University of Hyderabad, India*	1615-1630	**15549:** Feasibility of in-situ health monitoring for composite structure with embedded piezoelectric sensor networks **Khanh VO** *Nanyang Technological University, Singapore*	1625-1640	**15600:** A Calibration Method For LED Point Light Sources In Near-Field Photometric Stereo **Jing YU** *University of Wollongong, Australia*
1630 - 1645	**15625:** Detecting and Characterizing Spatter Particles on Additively Manufactured Surfaces in 3D Using X-Ray Computed Tomography and Deep Learning **Chaoyu DONG** *Nanyang Technological University, Singapore*	1630-1645	**15569:** Optical Imaging and Optical Manipulation Based on Microdroplets **Xixi CHEN** *Institute of Nanophotonics, Jinan University, China*	1640-1655	**15508:** Point cloud pair constraint registration algorithm based on directed distance function **Xingzhao WANG** *Shanghai University, China*
1645 - 1700	**15491:** Internal defect detection method based on dual-channel speckle interferometry **Tianyu YUAN** *Southeast University, China*	1645-1700	**15617:** Active thermal marker using thermal images of heated areas with visible semiconductor laser **Tomohiko HAYAKAWA** *Tokyo University of Science/ University of Tokyo, Japan*		
1700 - 1715	**15503:** Accuracy Analysis Of Stereo Calibration Methods With Large Field Of View **Wei KANG** *Southeast University, China*	1700-1715	**15613:** Parametric studies of liquid LIBS analysis for agricultural applications **Daryl LIM** *Nanyang Technological University, Singapore*		
1715 - 1730	**15572:** Robust acquisition-reduced iterative structured illumination microscopy **Jiaming QIAN** *Nanjing University of Science and Technology, China*	1715-1730	**15645:** Characterization of X-ray scintillation film **Timothy SHONG** *Singapore Institute of Manufacturing Technology, Singapore*		

SCIENTIFIC PROGRAMME

DAY 2: Wednesday, 29 November 2023

TIME	PROGRAMME
0800 - 1500	**Registration (Level 4, Main Foyer)**
0900 - 1700	**Exhibition** **(Changi Ballrooms, Level 4)**
0900 - 0945	**Plenary 3 (Atrium Ballroom, Level 4)** Session Chair: Chao ZUO **Publishing in Nature Journals** Dr Rachel WON *Spinger Nature Group, United Kingdom*
0945 - 1030	**Plenary 4 (Atrium Ballroom, Level 4)** Session Chair: Chao ZUO **Advances in high-accuracy three-dimensional dynamic deformation measurement and its applications for large structures** Prof Xiaoyuan HE *Southeast University, China*
1030 - 1045	**AM Break** **(Changi Ballrooms, Level 4)**
1045 - 1105	**Keynote 4 (Atrium Ballroom, Level 4)** Session Chair: Haixia WANG **Three-dimensional shape measurement of diffused/specular surface by combining fringe projection profilometry and phase measuring deflectometry** Prof Zonghua Zhang *Hebei University of Technology, China*
1105 - 1125	**Keynote 5 (Atrium Ballroom, Level 4)** Session Chair: Haixia WANG **Quantitative Phase Microscopy And Phase Correlation Spectroscopy for Biology** Prof Peng GAO *Xidian University, China*
1125 - 1145	**Keynote 6 (Atrium Ballroom, Level 4)** Session Chair: Haixia WANG **Research on Single Pixel Imaging Method for Moving Object** Dr Dongfeng SHI *Chinese Academy of Sciences, China*
1145 - 1330	**Lunch / Poster Session** **Presenter to Standby Poster (1230 - 1330 Hours)** **Exhibition Area (Changi Ballrooms, Level 4)**

DAY 2: Wednesday, 29 November 2023

TIME	PROGRAMME				
(1330 - 1530)	**Breakout 1** (Atrium Ballroom, Level 4)	**Breakout 2** (Seletar 2, Level 3)		**Breakout 3** (Seletar 3, Level 3)	
	SS14: Optical measurement and instrumentation *Session Chair: Yingjie YU*	**SS15:** Quantitative phase imaging *Session Chair: Chao ZUO*		**SS18:** X-ray optics and metrology *Session Chairs:* *Lei HUANG, Jumpei YAMADA*	
1330 - 1350	**15672 :** Development of optical measurement techniques for large aperture optics applied in high power laser systems **Shijie LIU** *Shanghai Institute of Optics and Fine Mechanics (SIOM), Chinese Academy of Sciences (CAS) ,China*	1330-1350	**15679:** Deep-learning Quantitative Phase Imaging for High Throughput Live-cell Imaging and Analysis **Renjie ZHOU** *The Chinese University of Hong Kong, Hong Kong, China*	1330-1350	**15474:** X-ray optics development and metrology at Shanghai Synchrotron Radiation Facility **Lian XUE** *Shanghai Advanced Research Institute, Chinese Academy of Sciences, Shanghai, China*
1350 - 1410	**15654 :** Trustworthy deflectometry: from precision to accuracy **Xiangchao Zhang** *Fudan University, China*	1350-1410	**15589:** Computational phase imaging for label-free 3D microscopy **Chao ZUO** *Nanjing University of Science and Technology, China*	1350-1410	**15587:** Development of stitching interferometry and ion beam figuring methods for high precision X-ray mirrors **Qiushi HUANG** *Tongji University, China*
1410 - 1430	**15668:** High precision multi-surface interferometry under non-integer sampling **Yingjie YU** *Shanghai University, China*	1410-1430	**15647:** High-quality dynamic phase imaging based on fourier ptychographic microscopy **Jiasong SUN** *Nanjing University of Science and Technology, China*	1410-1430	**15470:** Surface Interferometric Measurement Method With Higher Accuracy For X-ray Optical Applications **Xi HOU** *Institute of Optics and Electronics, Chinese Academy of Sciences, China*
1430 - 1445	**15518:** Visible wide-angle optical reconnaissance system design with high resolution, low distortion and high relative illumination. **Ying-Shun HSU** *National Central University, Taiwan*	1430-1450	**15681:** Multi-harmonic structured illumination based optical diffraction tomography (MHSI-ODT) **Peng GAO** *Xidian University, China*	1430-1450	**15662:** Requirements of the SHINE optics and consideration of their optical metrology **Xiaohao DONG** *Chinese Academy of Sciences, China*
		1450-1505	**15468:** Deep learning-enabled pixel super-resolution quantitative phase microscopy from single-shot intensity measurement **Jie ZHOU** *Nanjing University of Science and Technology, China*	1450-1510	**15678:** X-ray Optical Technology At High Energy Photon Source (HEPS) **Fugui YANG** *Institute of High Energy Physics CAS, China*
				1510-1525	**15642:** Developments of stitching interferometry techniques for the SHINE long X-ray mirrors surface shape measurement **Guang ZHOU** *Shanghai Institute of Applied Physics, Chinese Academy of Sciences, China*
1530 - 1545	**PM Break** **Exhibition Area (Changi Ballrooms, Level 4)**				

SCIENTIFIC PROGRAMME

DAY 2: Wednesday, 29 November 2023

TIME	PROGRAMME				
(1545 - 1745)	**Breakout 1** (Atrium Ballroom, Level 4)	**Breakout 2** (Seletar 2, Level 3)		**Breakout 3** (Seletar 3, Level 3)	
	SS2: 3D shape measurement based on fringe projection *Session Chair: Dongliang ZHENG*	**GT13:** Quantitative Phase Imaging *Session Chair: Liangcai CAO*		**GT6:** Image Processing and Deep Learning *Session Chair: Liyong REN*	
1545 - 1605	**15655 :** The way towards AI-based high-speed structured light 3D imaging **Shijie FENG** *Nanjing University of Science and Technology, China*	1545-1605	**15578:** Aberration-free high bandwidth holographic imaging **Liangcai CAO** *Tsinghua University, China*	1545-1605	**15479:** Real-time polarimetric de-scattering imaging technology: from thread framework to algorithm optimization and underwater demonstration **Liyong REN** *Shaanxi Normal University, China*
1605 - 1625	**15604 :** Multi-dimensional information sensing based on DIC-assisted fringe projection profilometry **Zhoujie WU** *Sichuan University, China*	1605-1620	**15663:** High-speed 3D imaging and metrology: from classical fringe projection to deep learning approaches **Chao ZUO** *Nanjing University of Science and Technology, China*	1605-1620	**15488:** Polarization demosaicking algorithm based on polarization channels correlation **Yanji YI** *University of Science and Technology of China*
1625 - 1645	**15671 :** 3D Reconstruction Of Dynamic Object Based On Improved Deep Optical Flow Tracking **Lei LYU** *Henan University of Technology, China*	1620-1635	**15461:** Transport of intensity diffraction tomography with non-interferometric synthetic aperture for three-dimensional label-free microscopy **Jiaji LI** *Nanjing University of Science and Technology, China*	1620-1635	**15505:** A Two-Stage Deep Learning Method for Foreign Object Detection and Localization **Zhenbiao WANG** *Advanced Remanufacturing & Technology Centre (ARTC), Singapore*
1645 - 1700	**15616:** Phase-shift Error Estimation Based On Deep Learning **Ketao YAN** *Changzhou University, China*	1635-1650	**15622:** Differential phase contrast quantitative phase imaging based on optimal modulation of asymmetric illumination **Yao FAN** *Nanjing University of Science and Technology, China*	1635-1650	**15664:** CycleSR: Unsupervised Learning for 3D fingerprint Super-Resolution **Haixia WANG** *Zhejiang University of Technology, China*
1700 - 1715	**15590:** Indoor simultaneous localization and mapping based on fringe projection profilometry. **Yang ZHAO** *Nanjing University of Science and Technology, China*	1650-1705	**15626:** High-throughput artifact-free slightly off-axis holographic imaging based on Fourier ptychographic reconstruction **Qian SHEN** *Nanjing University of Science and Technology, China*	1650-1705	**15628:** Microscopic Spectra Measurement Based on Coherence Scanning Interferometry **Cheng CHEN** *Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, China*
1715 - 1730	**15568:** Prototype of High-brightness Fringe Projector Using Line LED Device and Cylindrical Lens Array **Motoharu FUJIGAKI** *University of Fukui, Japan*	1705-1720	**15460:** Non-interferometric optical diffraction tomography with Fourier ptychography **Shun ZHOU** *Nanjing University of Science and Technology, China*	1705-1720	**15631:** Design of Point Cloud Data Structures for Efficient Processing of Large-Scale Point Clouds **Yixuan WANG** *Beihang University, China*
1730 - 1745	**15619:** Theoretical Analysis and Discussion of The Measurement Methods in Fringe Projection Profilometry **Shenzhen LYU** *Nanyang Technological University, Singapore*				
1900 - 2130	**Conference Dinner (Tien Court, Copthorne King's Hotel)** Meeting Point: Holiday Inn Atrium Main Lobby, Level 1 @ 18:00 hours, @ 18:15 hours				

SCIENTIFIC PROGRAMME

DAY 3: Thursday, 30 November 2023

<table>
<tr><th>TIME</th><th colspan="6">PROGRAMME</th></tr>
<tr><td>0800 - 1000</td><td colspan="6">Registration (Level 4, Main Foyer)</td></tr>
<tr><td>0900 - 1600</td><td colspan="6">Exhibition
(Changi Ballrooms, Level 4)</td></tr>
<tr><td rowspan="2">(0900 - 1030)</td><td>Breakout 1
(Atrium Ballroom, Level 4)</td><td colspan="2">Breakout 2
(Seletar 2, Level 3)</td><td colspan="2">Breakout 3
(Seletar 3, Level 3)</td></tr>
<tr><td>SS12:
Micro/Nano-Mechanical measurement and characterization by optical/spectral methods
Session Chair: Wei HE</td><td colspan="2">SS9:
Imaging through scattering media and non-line-of-sight imaging
Session Chair: Jing HAN</td><td colspan="2">GT12:
Optical Measurement Methods
Session Chair: Satoru YONEYAMA</td></tr>
<tr><td>0900 - 0920</td><td>15657:
Uses of image features in digital image correlation for deformation measurement
Zhenyu JIANG
South China University of Technology, China</td><td>0900 -0920</td><td>15463:
Fingertip OCT Image Acquisition and Enhancement
Haixia WANG
Zhejiang University of Technology, China</td><td>0900 -0920</td><td>15559:
Finite strain measurement and stress mapping for thin plate specimen using digital image correlation
Satoru YONEYAMA
Aoyama Gakuin University, Japan</td></tr>
<tr><td>0920 - 0940</td><td>15652:
New photomechanics methods in characterizing high-temperature fatigue crack growth behavior of nickel-based superalloys
Wei HE
Hunan University, China</td><td>0920-0940</td><td>15462:
Exploring the range of optical memory effect by deep learning
Wenqi HE
Shenzhen University, China</td><td>0920-0935</td><td>15496:
A Novel Method to Parallel Beam Generation for Roll Angle Measurement
Shaohua MA
Hefei University of Technology, China</td></tr>
<tr><td>0940 - 0955</td><td>15547:
Measurement of geometric and mechanical parameters for fatigue microcrack based on tracking platform
Xinxing SHAO
Southeast University, China</td><td>0940-0955</td><td>15469:
Modelling multiple scattering of polarized light with random matrices
Niall BYRNES
Nanyang Technological University, Singapore</td><td>0935-0950</td><td>15629:
Extract focus variation data from coherence scanning interferometric measurement
Jiayu LIU
Shanghai Jiao Tong University, China</td></tr>
<tr><td>0955 - 1010</td><td>15540:
Evolution of diffusion and induced stress and its effect on the lithium-storage performance of graphite electrode
Prof Haimei XIE
Tianjin University, China</td><td>0955-1010</td><td>15580:
Multi-strategy close range 3-D shape measurement in turbid water based on structured light
Nenqing LYU
Nanjing University of Science and Technology, China</td><td>0950-1005</td><td>15524:
Uncertainty analysis and optimization design of large-range laser triangulation displacement sensor applied to dynamic object
Zhuojiang NAN
Shanghai Jiao Tong University, China</td></tr>
<tr><td></td><td></td><td></td><td></td><td>1005-1020</td><td>15528:
Two-dimensional Angle Measurement with Sub-arcsecond Precision and MHz Acquisition Rate Using Heterodyne Interferometry with Optical Frequency Comb
Chen LIN
Tsinghua University, China</td></tr>
<tr><td>1030 - 1045</td><td colspan="6">AM Break
(Changi Ballrooms, Level 4)</td></tr>
</table>

SCIENTIFIC PROGRAMME

DAY 3: Thursday, 30 November 2023

TIME	PROGRAMME				
(1045 - 1215)	**Breakout 1** (Atrium Ballroom, Level 4)	**Breakout 2** (Seletar 2, Level 3)		**Breakout 3** (Seletar 3, Level 3)	
	SS8: High-precision optical measurement *Session Chair: Xiangchao ZHANG*	**GT2:** Biomedical Optics and Imaging *Session Chair: Yongtao LIU* **GT3:** Computer Vision Techniques *Session Chair: Yongtao LIU*		**SS1:** 2D, 3D and Volumetric digital image correlation and their applications *Session Chair: Zhenyu JIANG* **GT10:** Optical Component and System Simulation *Session Chair: Zhenyu JIANG* **GT15:** Ultrafast Lasers and Applications *Session Chair: Zhenyu JIANG*	
1045 - 1100	**15522:** Smoothed-truncated-sine(STS) Pattern For Accuracy Improvement In Sinusoidal Fringe Projection Profilometry **Zhihu LI** *Tsinghua University, China*	1045-1100	**15656:** Upconversion Multimodality super resolution microscopy **Yongtao LIU** *Nanjing University of Science and Technology, China*	1045-1105	**15489:** The theory and error analysis of crack propagation measurement for brittle materials based on virtual principal strain field **Liuning GU** *Southeast University, China*
1100 - 1115	**15550:** High-precision deflectometry: challenges and prospects **Xiangchao ZHANG** *Fudan University, China*	1100-1115	**15457:** Disordered Surface Plasmon Sensor for Scattering Enhanced Single Particle Detection **Matthew FOREMAN** *Nanyang Technological University, Singapore*	1105-1125	**15576:** Transformer-based deep learning for digital image correlation **Zhenyu JIANG** *South China University of Technology, China*
1115 - 1130	**15523:** A Weighted Least Squares Algorithm For Wrapped Phase Retrieval In Sinusoidal Fringe Projection Profilometry **Zhihu LI** *Tsinghua University, China*	1115-1130	**15566:** Light-induced Acceleration of Biomolecular Recognitions for Proteins and Nanoscale Extracellular Vesicles **Takuya IIDA** *Osaka Metropolitan University, Japan*	1125-1140	**15548:** New Virtual Model as A Built-in Thin Lens Component of Optical Software to Balance Component Aberrations Between Different Zoom Positions of Optical Lenses **Chaohsien CHEN** *National Kaohsiung University of Science and Technology, Taiwan*
1130 - 1145	**15581:** Spectral mechanical investigation of the elastic interface between a MoS2/graphene heterostructure and a soft substrate **Huadan XING** *Tianjin University, China*	1130-1145	**15586:** Opto-acousto-fluidic microplatform for label-free high-throughput detection and sorting of microalgal cells **Xiudong DUAN** *China University of Geosciences, Wuhan, China*	1140-1155	**15649:** Versatile GHz burst-mode operation in high-power femtosecond laser for industrial applications **Deividas ANDRIUKAITIS** *EKSPLA, Lithuania*
		1145-1200	**15641**: Spinning disk confocal microscopy image stitching **Mengjun LIU** *Advanced Remanufacturing and Technology Centre (ARTC), Singapore*	1155-1210	**15637:** A simulation on quasi-phase-matched high-harmonic generation in gas-filled hollow core waveguide **Qiandong RAN** *Singapore Institute of Manufacturing Technology, Singapore*
1215 - 1330	**Lunch/Posters on Display Exhibition Area (Changi Ballrooms, Level 4)**				

SCIENTIFIC PROGRAMME

DAY 3: Thursday, 30 November 2023

TIME	PROGRAMME				
(1330 - 1530)	**Breakout 1** (Atrium Ballroom, Level 4)	**Breakout 2** (Seletar 2, Level 3)		**Breakout 3** (Seletar 3, Level 3)	
	SS7: High-accuracy optical deformation measurement of large engineering structures *Session Chairs:* *Xinxing SHAO, Qinwei MA*	**SS16:** Single-pixel imaging and optical encoding *Session Chair: Wen CHEN*		**GT12:** Optical Measurement Methods *Session Chair: Fujun YANG*	
1330 - 1350	**15537:** Bridge deflection measurement by drone aerial photography using the sampling moire method **Shien RI** *National Institute of Advanced Industrial Science, Japan*	1330-1350	**15492:** High-quality object reconstruction based on single-pixel imaging in highly dynamic scattering environments **Yin XIAO** *The Hong Kong Polytechnic University, Hong Kong, China*	1330-1345	**15515:** Using three-dimensional electronic speckle pattern interferometry to study Quasi-static response of two-dimensional dense granular packings to localized force **Fujun YANG** *Southeast University, China*
1350 - 1410	**15624:** Camera Array Based Super Spatio-temporal Resolution Videometrics For Deformation Measurement Of Large Structures **Qinwei MA** *Beijing Institute of Technology, China*	1350-1410	**15660:** High Speed Photoacoustic Microscopy based on Single Pixel Imaging Method **Chengbo LIU** *Chinese Academy of Sciences, China*	1345-1400	**15614:** Illumination Variation Robust Circular Target Based on Digital Image Correlation Method **Shuai DONG** *Changsha University of Science and Technology, China*
1410 - 1430	**15658:** Adaptive fringe projection moiré method for large structure morphology measurement **Chen SUN** *Shanghai Jiao Tong University, China*	1410-1425	**15499:** Optical pixel-to-plane encoding with neural network for ghost transmission through complex scattering media **Yang PENG** *The Hong Kong Polytechnic University, Hong Kong, China*	1400-1415	**15630:** Compact ARS probe to measure roughness of smooth surfaces **Zihan CHEN** *Shanghai Jiao Tong University, China*
1430 - 1450	**15603:** Simulation and experimental analysis of the precision for the standardized calibration **Cong LIU** *Nanjing University of Science and Technology, China*	1425-1440	**15501:** Random Encoding with Modified Gerchberg-Saxton Algorithm for Accurate Ghost Transmission through Complex Scattering Media **Yining HAO** *The Hong Kong Polytechnic University, Hong Kong, China*	1415-1430	**15632:** Absolute testing of optical flats using a minimum norm least squares solution **Xiaoyue QIAO** *Shanghai Institute of Optics and Fine Mechanics,* *Chinese Academy of Sciences, China*
1450 - 1510	**15571:** Full-field deformation measurement of large wing structure based on the multi-camera network with non-overlapping fields of view **Yan LIU** *Shenzhen University, China*	1440-1455	**15506:** Secured optical data transmission through dynamic scattering media using pixel-to-plane optical data encoding **Yonggui CAO** *The Hong Kong Polytechnic University, Hong Kong, China*	1430-1445	**15634:** Quality Inspection and Assembly Sequence Optimization of Revolved Thin-walled Parts Based on Point Clouds **Zhaoyuan MA** *Beihang University, China*
1510 - 1525	**15560:** Target based multi-camera stereo digital image correlation: calibration and registration **Zhuoyi YIN** *Southeast University, China*	1455-1510	**15464:** Image-free feature tracking by Single-pixel Imaging Technologies **Mingyang NI** *University of Science and Technology of China, China*	1445-1500	**15516:** Direct strain measurement method based on the correlation of defocused laser speckle pattern **Wenxin HU** *Shenzhen MSU-BIT University, China*
				1500-1515	**15584:** A Transmission- Reflection Photoelastic Combined Technique for Internal Stress Analysis of Inorganic Flexible Electronic Bilayer Structures **Quanyan HE** *Tianjing University, China*
1530 - 1545	**PM Break** **Exhibition Area (Changi Ballrooms, Level 4)**				

DAY 3: Thursday, 30 November 2023

TIME	PROGRAMME				
(1545 - 1745)	**Breakout 1** (Atrium Ballroom, Level 4)		**Breakout 2** (Seletar 2, Level 3)		**Breakout 3** (Seletar 3, Level 3)
	SS13: Optical dynamic measurement *Session Chair: Yu FU*		**SS16:** Single-pixel imaging and optical encoding *Session Chair: Wen CHEN* **GT1:** 3D Image Acquisition and Display *Session Chair: Wen CHEN*		**SS4:** Advances in Moiré method and its applications *Session Chair: Hongye ZHANG* **SS17:** Infrared thermography and structural health monitoring *Session Chair: Hongye ZHANG*
1545 - 1605	**15623:** Research and application of optical heterodyne interferometry with high precision **Wenxi ZHANG** *Chinese Academy of Sciences, Aerospace Information Research Institute, China*	1545-1605	**15564:** Some Explorations for High-speed Fringe Projection Profilometry **Yongkai YIN** *Shandong University, China*	1545-1605	**15585:** TEM Moiré method and its application **Hongye ZHANG** *Beijing Forestry University, China*
1605 - 1625	**15673:** Flexible and high-intensity photoacoustic transducer for contact-free laser ultrasonic inspection **Guo SHIFENG** *Shenzhen Institute of Advanced Technology, China*	1605-1620	**15517:** Image-free multi-object tracking based on multi-channel single-pixel imaging system **Yu CAI** *University of Science and Technology of China, China*	1605-1625	**15530:** Microscale strain distribution measurement before and after crack and delamination occurrence in CFRP laminates by multiplication sampling moire method **Xinyun XIE** *Beihang University, China*
1625 - 1645	**15646:** Full-field vibration measurement based on a combination of laser and imaging technology **Yu FU** *Shenzhen University, China*	1620-1635	**15611:** An optical image encryption method based on Fourier single-pixel imaging and iterated phase retrieval algorithm **Tianyu ZENG** *Xi'an University of Technology, China*	1625-1640	**15567:** Sampling moiré method and its application in 2D/3D deformation measurement **Ru CHEN** *Tsinghua university, China*
1645 - 1700	**15543:** Method for measuring full-field vibration of rotating components using laser and image fusion **Zeren GAO** *Shenzhen University, China*	1635-1650	**15539:** Hardware-based Fusion Sensing System for Lidar and Imaging **Yuanzu WANG** *Tsinghua University, China*	1640-1655	**15487:** Infrared colorimetric temperature measurement based on a two-band metalens **Zhendong LUO** *University of Science and Technology of China, China*
1700 - 1715	**15476:** Modeling of Mechanoluminescent Strain Sensing Mechanisms and Their Application to Vibration Modal Measurements **Bing CHEN** *Shenzhen University, China*	1650-1705	**15575:** Microscopic fringe projection and applications in high-accuracy 3D measurements **Yan HU** *Nanjing University of Science and Technology, China*	1655-1710	**15653:** Non-destructive Evaluation using Continuous Laser-Line Scanning Thermography with an Improved Data Processing Algorithm **Li CHAOYI** *Jiangsu University, China*
1715 - 1730	**15482:** Improved Speckle Interferometry Method Based On High-Speed Camera And Laser Doppler vibrometers **Ruyue ZHANG** *University of Science and Technology of China, China*			1710-1725	**15512:** Online Detection Method for Additive Manufacturing Printing Based on Near-Infrared Dual-wavelength Thermometry **Wei FENG** *Beijing Institute of Technology, China*
				1725-1740	**15639:** A method for identifying precursors information on infrared radiation of instability and failure in wood **Jian ZHAO** *Beijing Forestry University, China*

SCIENTIFIC PROGRAMME

DAY 4: Friday, 1 December 2023

TIME	PROGRAMME
(0930 - 1430)	**Site visit to** **d'Optron Pte Ltd and The Photonics Institute, Nanyang Technological University** **Registration of Attendance @ ImageX/d'Optron Booth No. T6** (Exhibition Area, Changi Ballrooms, Level 4) **Tuesday – Wednesday, 28 – 29 November 2023, 0930 – 1430 Hours**
0930	**Visit to d'Optron Pte Ltd** 8 Cleantech Loop, Block E, #06-72 Cleantech 3, Singapore 637145 (No transport is provided)
1000	**Contributions of Holography** **Dr Peter De GROOT** *Zygo Corporation, United States*
1100	**Tour of d'Optron Pte Ltd**
1200	**Coach Departs for Nanyang Technological University** **Lunch at NTU Canteen (Free and Easy and on Pax Account)**
1330	**Tour of The Photonics Institute, Nanyang Technological University**
1430	**End of Programme**

POSTER ABSTRACT LISTING

Poster on Display

Venue: Poster/Exhibition Area (Changi Ballrooms), Level 4
Time: 28-29 November 2023, 09:00 - 17:00 hours
30 November (0900 - 1600 Hours)
Presenter to standby Poster: Wednesday, 29 November 2023, 1145 - 1330 hours

SPECIAL SESSION PAPERS				
Abstract No	**Family Name**	**First Name**	**Country**	**Title of Abstract**
15552	CHAI	Xuanyu	China	Zernike Polynomials Fitting of Arbitrary Shape Wavefront
15607	DAI	Jiacheng	China	A chromatic confocal bimodal signal pattern based on offset slit filtering
15527	FU	Yu	China	Suppression of speckle noise in laser Doppler vibrometry by signal diversity and dynamic ellipse fitting
15615	JIANG	Zishan	China	A multi-image authentication scheme based on the phase-only hologram
15554	LIU	Xiaoli	China	Body scanning and anthropometric data extraction based on a multi-view structred light 3D imaging system
15525	WU	Gaoxu	China	Measurement depth maximization of geometric constraint based on phase-to-space error analysis
15608	WU	Yunquan	China	Simultaneous thickness and refractive index measurement based on chromatic confocal aberration compensation
15545	YU	Wenjun	China	Phase retrieving by extracting Zernike coefficients from two random phase-shifting interferograms based on deep learning
15504	ZHAO	Changzhe	China	Development and Characterization of Stress-free Laue Diffraction Crystal for X-ray Beam Splitting
15592	ZHAO	Yang	China	Adaptive-resolution-based high-resolution indoor 3D perceiving in fringe projection profilometry
15546	ZHOU	Yonghao	China	Fast anti-turbidity underwater topography measurement based on structured light
15551	ZHU	Yaowen	China	Speckle Pattern Interferometry excited by pulse laser for Crack Size Prediction

POSTER ABSTRACT LISTING

Poster on Display

Venue: Poster/Exhibition Area (Changi Ballrooms), Level 4
Time: 28-29 November 2023, 09:00 - 17:00 hours
30 November (0900 - 1600 Hours)
Presenter to standby Poster: Wednesday, 29 November 2023, 1145 - 1330 hours

GENERAL TRACK PAPERS				
Abstract No	**Family Name**	**First Name**	**Country**	**Title of Abstract**
15636	CHENCHEN	Yan	Singapore	Research on Dimension Measurement Based on 3D Point Cloud
15685	HU	Jing	China	Remote sensing image target detection via Gaussian distance loss
15684	HU	Jing	China	Hyperspectral Anomaly Detection Based on Background Purification and Spectral Feature Extraction
15475	HUA	Zhijie	China	Single-shot microscopic autofocus focusing on image detail features
15598	KIM	Miyoung	Korea, Rep.	Application of depth map hologram generating technique for developing a large hologram film master
15609	NAIK	Megha	India	In-house Developed Ultra-Sensitive Laser Stimulated Fluorescence System for Metabolic Profiling
15557	PENG	Junchang	China	Diffraction model-driven neural networks trained using low-frequency functions enhanced datasets for multi-depth and high-quality computer-generated holography
15610	PILLAI	Anusha	India	3D Quantitative Phase Imaging for studying Human Red Blood Cells
15542	SANGEETH	Suchand	India	Tunable All-Optical Diode Action in Polymeric Photonic Crystals with Photonic Band Edge Effects
15495	SANGEETH	Suchand	India	Tuning the third-order nonlinear optical properties of methyl orange via adding plasmonic nanoparticles and protonation
15682	WOOCHAI-YAPHUM	Bunyarit	Thailand	Predictions gender of Moina by using digital holography and deep learning.
15633	YONG	Tang	China	3D measurement of large and complex parts based on phase matching and global marker point ,kmmmmmmm registration

icOPEN2023 (Plenary)

Topic: Plenary Talk
Abstract No: 15651

Digital holographic metrology for imaging acoustics & vibrations

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Content

We present recent results for the measurement of acoustic fields and vibrations by using high-speed digital holographic interferometry. We discuss on the decorrelation noise in the measurement data and filtering opportunities provided by deep learning architectures. We consider applications related to the metrology of transient vibrations with highlight of synchronous digital holography and asynchronous digital holography.

Keywords: digital holography, holographic interferometry, phase imaging, decorrelation noise, transient vibrations

Topic: Plenary Talk
Abstract No: 15675

Testing optics with interferometry and tunable-wavelength lasers

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Content

In the 1990’s, it was still common for laser Fizeau interferometers of large size--capable of measuring parts more than 50 cm in diameter—to rely on a visual or automated analysis of static fringe patterns. Phase shifting interferometry, which traditionally require mechanical motions of the reference optic or the part itself, is impractical for such large systems. The solution is to sweep the wavelength to generate phase shifts without mechanical motions in the interferometer.

Further advances in wavelength-tuned interferometry have launched a series of revolutionary innovations in optical testing. Today, Fourier transform methods with dynamic wavelength tracking allow for simultaneous measurement of the front and back surfaces as well as the material homogeneity of plane-parallel parts. Applications include quality testing of glass substrates for computer rigid disk drives, planar waveguides for augmented reality systems, cover glass for portable displays, and high-precision optical flats. Model-based data analysis significantly enhances environmental robustness, and absolute distance measurements of part position optimize instrument focus automatically.

In this presentation, I review the principles, history, applications, and current state of the art for tunable-wavelength interferometry, including on-going research and perspectives on future developments.

Topic: Plenary Talk
Abstract No: 15676

Advances in high-accuracy three-dimensional dynamic deformation measurement and its applications for large structures

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Content

High-accuracy panoramic three-dimensional dynamic deformation measurements are of considerable significance for studying the mechanical properties of large or ultra-large structures. As a simple, non-contact, and high-precision full-field deformation measurement technology, three-dimensional digital image correlation (3D-DIC) can provide an effective measurement method for large-scale structural deformation measurement. This presentation will introduce the basic principle of 3D-DIC measurement and present key technical advancements in the panoramic deformation measurement of large structures with multiple cameras. These advancements include large-scale speckle fabrication, 3D calibration of large field-of-view, coordinate unification of multi-camera systems, and real-time calibration of camera extrinsic parameters. Furthermore, this paper presents practical applications of high-accuracy 3D dynamic deformation measurements for large structures in civil engineering and aerospace engineering fields, such as the assessment of the cassette structure in seismic shaking table tests, panoramic high-speed deformation measurement of suspension cable dome structures in progressive collapse tests, and panoramic deformation measurement of cabin structures of launch vehicles in load tests. Using high-accuracy 3D dynamic deformation measurements for large structures provides a reliable experimental method for seismic performance analysis, mechanical modelling of large structures, and in-depth study of failure mechanisms.

Topic: Plenary Talk
Abstract No: 15677

Publishing in Nature journals

Rachel Won*[1]
[1]-/ Nature Photonics/ Korea, Rep. (대한민국)

Content

In this talk, Rachel will tell you all you need to know about publishing your work in *Nature* journals, right from preparing your manuscript and options you have during your submission, through to the editorial and review processes.

icOPEN2023 (General Track)

Topic: GT1: 3D Image Acquisition and Display
Abstract No: 15539

Hardware-based Fusion Sensing System for Lidar and Imaging

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Content

Intelligent unmanned systems have become a major focus in current technological development, with a key emphasis on their ability to perceive and comprehend the external environment. The foundation of this perception lies in target identification, tracking, and precise positioning. While lidar technology excels at acquiring accurate distance information about targets, it falls short in capturing color, texture, and other detailed information. On the other hand, multispectral imaging can provide comprehensive environmental details but lacks distance information. Integrating lidar and image sensors to collect and process simultaneous distance and multispectral data has posed a significant challenge. At present, most research in this field centers around developing algorithms to calibrate and align data from diverse sensors in both temporal and spatial dimensions. Synchronizing data from multiple sensors proves to be a complex undertaking. This paper presents a novel approach to address this challenge through the introduction of a hardware fusion multispectral-lidar system. By designing an optical system and hardware control system, the system achieves point matching between laser point clouds and image pixels, enabling data-level fusion. The proposed approach overcomes existing technological limitations and enables high-precision space-time synchronization.

Keywords: Lidar;Multispectral;Point cloud image fusion;Space-time synchronization

Topic: GT1: 3D Image Acquisition and Display
Abstract No: 15557

Diffraction model-driven neural networks trained using low-frequency functions enhanced datasets for multi-depth and high-quality computer-generated holography

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Content

Unsupervised learning-based computer-generated holography (CGH) provides an effective training method that reduces the reliance on labeled datasets. However, most existing learning-based algorithms still struggle to produce high-quality holograms due to the difficulty of deep neural networks in learning the task of phase recovery across the frequency and space domains. Here, we present a diffraction model-driven neural network (LFE-Holo) trained using a low-frequency functions enhanced dataset to generate phase-only holograms (POH). Since the convolution operator is like a high-pass filter, it causes a bias to the spectrum and poor learning of low-frequency functions. LFE-Holo employs a data augmentation technique by utilizing a diverse set of low-pass filtered images with various masks to facilitate the learning of low-frequency functions by the convolution operator. If the ability of the convolution operator to learn low-frequency functions is improved, it can help to improve the quality of the reconstructed images. Due to the angular spectrum propagation being incorporated into the neural network, learning-based CGH can be trained in an unsupervised manner without the need for a dataset. LFE-Holo is free to choose the number of depth layers and generate 3D holograms based on the target amplitude image as well as the corresponding depth image. Both monochromatic and panchromatic optical experiments show that the proposed method can effectively reconstruct multi-depth images and suppress artifacts of the reconstructed images.

Keywords: holography display;deep learning

Topic: GT1: 3D Image Acquisition and Display
Abstract No: 15564

Some Explorations for High-speed Fringe Projection Profilometry

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Content

Fringe projection profilometry (FPP) is one of the typical techniques for 3D shape measurement. Our recent works about improving the speed of FPP are presented. The basic idea to improve the speed of multi-frame fringe projection is to reduce the frame number required for phase calculation. The first work is algorithm research on phase calculation with two-step phase-shifting. A model of two-step phase-shifting is established by analyzing the work process of FPP system and introducing appropriate constrain, and then the accuracy will be improved by optimizing the contrast of the fringe. Another strategy to break the speed limitation of classic system is coding and computational imaging. The second work is the study of fringe projection based high-speed single-pixel 3D imaging. According to the time-resolved single-pixel imaging technology, a series of time-varying images can be reconstructed by using the correlation between periodically repeated dynamic scenes and synchronously switched modulation patterns. Combining this technique with the Fourier transform profilometry (FTP), we successfully achieved 3D imaging at the frame rate up to 2,000,000 fps for a blade rotating at 4,800 rpm. The third work is the combination of the snapshot compressive imaging (SCI) and FTP. SCI can recover multiple images from single coded frame. We propose a SCI-FTP system that can encode multiple deformed fringe images into the data of snapshot and then reconstruct dynamic shapes from this frame. It is a promising approach of high-speed 3D imaging that can break the frame rate cap of the camera.

Keywords: 3D imaging; fringe projection profilometry (FPP); two-step phase-shifting; single-pixel imaging; snapshot compressive imaging

Topic: GT1: 3D Image Acquisition and Display
Abstract No: 15573

Deep learning-enabled structured light system for single-shot absolute 3D shape measurement

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Content

In this work, we present a deep learning-enabled real-time structured light system for single-shot absolute 3D shape measurement. By constructing a lightweight convolutional neural network and deploying the trained model in a self-designed structured light system, high-precision phase information extraction and real-time 3D data acquisition can be achieved directly from a single-frame fringe image. From the perspective of 3D imaging speed and measurement accuracy, we comprehensively analyze the performance of the deep learning-based system and compare it with state-of-the-art structured light systems. Experimental results demonstrate that the deep learning-enabled structured light system can directly perform the single-shot robust and unambiguous phase retrieval process and high-quality absolute 3D surface information of the objects under fast and dynamic scenes. Thanks to its single-shot nature, this method is fundamentally immune to phase-shifting errors induced by object motion and is suitable for dynamic 3D imaging of rapidly moving objects.

Keywords: Structured light system, single-shot absolute 3D shape measurement, deep learning, phase retrieval

Topic: GT1: 3D Image Acquisition and Display
Abstract No: 15575

Microscopic fringe projection and applications in high-accuracy 3D measurements

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Content

Microscopic 3D imaging using fringe projection has higher measurement accuracy because of the extra-dense fringe provided by lenses with large magnification, low distortion, and extended depth of field. The Scheimpflug principle is commonly used in single-camera-based and multi-camera-based microscopic fringe projection systems to extend the mutual overlap range of different views in the object space. Here, we introduce microscopic fringe projection systems and perform applications in high-accuracy 3D measurements. The projector calibration method which is based on the geometric center extraction of the white squares on the checkboard is introduced. The Scheimpflug telecentric camera calibration is also proposed based on affine projection and is applied in the multi-camera-based microscopic fringe projection systems. The experimental results of 3D imaging of different industrial parts are also provided, which may provide a reference for the system design in implementing other related industrial applications

Keywords: Structured light, 3D imaging, camera calibration, Scheimpflug, telecentric

Topic: GT1: 3D Image Acquisition and Display
Abstract No: 15598

Application of depth map hologram generating technique for developing a large hologram film master

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Content

Recently, AR/VR and hologram-related technologies are drawing attention along with the practical application of 5G wireless communication. In particular, holography uses light diffraction and interference, and is a next-generation display technology that records the distribution of light reflected or diffracted from real images and reproduces real images on space. Holography is used as core technologies in various fields such as medical, transportation, display, culture, advertising, security, manufacturing, etc.

In this study, in order to develop a large hologram film master using Computer-Generated Hologram(CGH), hologram interference patterns were designed using depth map hologram generation technology that can reduce the amount of calculation required for high resolution image processing. The number of pixels that can be worked on in a conventional program was limited to a total of 900 million pixels, 30,000 each by width and length, and 21mm diameter based on 0.7μm pixels was the limit. In order to overcome the limitations and make a large hologram film master, we added the function of uploading images consisting of 20,000 to 30,000 pixels in depth map hologram generation program and expanding the number of pixels to 100,000. The added functionality allowed multiple images of less than 30,000 pixels to be generated with split CGH. In addition, we developed a large hologram film master with a depth of 10 billion pixels composed of 0.7 μm pixel size and 70 mm diameter through divided images.

Keywords: Holography; Hologram; film master; Computer-Generated Hologram; Depth map;

Topic: GT2: Biomedical Optics and Imaging
Abstract No: 15457

Disordered Surface Plasmon Sensor for Scattering Enhanced Single Particle Detection

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Content

Scattering in disordered systems can give rise to a rich set of mesoscopic phenomena not seen in more regular structures, such as coherent backscattering, Anderson localisation and long range correlations. The speckle-like intensity patterns generated from random scattering are known to exhibit high sensitivity to configurational changes in the scattering environment, such as nano-displacements of a single scatterer. This is especially true in two dimensional systems, where localisation effects can occur even when disorder is weak. Surface plasmon based systems therefore offer great potential in the area of single particle sensing and tracking. Traditionally, surface plasmon resonance sensors have been limited to bulk sensing, however, in this work we demonstrate how random scattering of surface plasmons can enable us to go further and detect binding of individual nanoparticles to the surface of a randomly nanostructured sensor. Our approach exploits both strong-light matter interactions associated with confined plasmonic fields, and optical interference to improve sensitivity.

In this talk we will present experimental results as a proof of principle for sensing of single gold and polystyrene nanoparticles binding to a gold nanoisland substrate. Furthermore, using a coupled dipole model, we theoretically analyse the role played by multiple scattering and study the interplay between localisation, coherent coupling and absorption. We will discuss how, through optimal design of the random sensor surface, further sensitivity enhancements of several orders of magnitude are possible.

Keywords: single particle detection, surface plasmon sensor, multiple scattering

Topic: GT2: Biomedical Optics and Imaging
Abstract No: 15497

Parallel synthetic aperture transport-of-intensity diffraction tomography with annular illumination

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Content

Transport-of-intensity diffraction tomography (TIDT) is a recently developed label-free computational microscopy technique that retrieves high-resolution three-dimensional (3D) refractive index (RI) distribution of biological specimens from 3D intensity-only measurements. However, the non-interferometric synthetic aperture in TIDT is generally achieved sequentially through the acquisition of a large number of through-focus intensity stacks captured at different illumination angles, resulting in a very cumbersome and redundant data acquisition process.

To overcome the traditional redundant process, we present a parallel implementation of a synthetic aperture in TIDT (PSA-TIDT) with matched annular illumination. We found that matched annular illumination provides a mirror-symmetric 3D optical transfer function, indicating the analyticity in the upper half-plane of the complex phase function, which allows for recovery of the 3D RI from a single intensity stack. The proposed parallel aperture synthesis strategy can reduce the system's data requirement over 120 times than existing work, which not only relieves the burden on storage but also achieves computational acceleration of 3D tomographic reconstruction.

To validate the effectiveness of PSA-TIDT, we conducted high-resolution tomographic imaging of various unlabeled biological samples, including human breast cancer cell lines (MCF-7), human hepatocyte carcinoma cell lines (HepG2), Henrietta Lacks (HeLa) cells, and red blood cells (RBCs). Based on these results, the proposed method is more efficient and has an excellent performance in the reconstruction of 3D RI distribution of biological specimens. This advancement in TIDT has the potential to significantly enhance our understanding of cellular dynamics and facilitate various applications in biomedical research and diagnostics.

Keywords: Three-dimensional imaging; transport of intensity diffraction tomography; refractive index imaging; annular LED illumination

Topic: GT2: Biomedical Optics and Imaging
Abstract No: 15534

Development of Light-induced Detection Method for Viruses with Plasmonic Nano-bowl Substrate

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Content

Recently, the COVID-19 pandemic has given a significant impact on human beings. Although the lateral flow immunoassay with the reaction of an antigen (virus) and an antibody with localized surface plasmon resonance (LSPR) is widely used due to the simplicity and high usability, the sensitivity is too low to detect a small amount of viruses at the early stage of disease. On the other hand, "optical condensation" attracts attention since this technology can assemble biological samples such as bacteria and viruses for rapid and highly sensitive detection by light-induced force and light-induced convection (LIC). Paying attention to this technology, in addition to LIC, we have developed a nano-bowl substrate (PNS) exhibiting prominent LSPR to enhance the detection sensitivity. Our developed PNS has metallic nanostructures with non-through-holes of 500 nm diameter, where the optical electric field can be enhanced by the coupling of LSPR. In addition, LIC can be generated by local heating with several mW laser for optical condensation due to its unique structure of PNS. For the selective detection of a particular kind of virus, antibody-modified beads were assembled onto the PNS by the first laser irradiation to create trapping site before second laser irradiation for optical condensation of targets. We tried to assemble virus-mimicking nanoparticles (VMNPs) by such a two-step optical condensation. The selective detection of VMNPs was successfully demonstrated with 100-fold sensitivity within less than 5 minutes. This achievement will improve a variety of analytical technologies for various types of infectious disease.

Keywords: Plasmonics;Optical condensation;Plasmon;Viruses

Topic: GT2: Biomedical Optics and Imaging
Abstract No: 15566

Light-induced Acceleration of Biomolecular Recognitions for Proteins and Nanoscale Extracellular Vesicles

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Content

Extracellular vesicles (EVs) such as exosomes and ectosomes are potential biomarkers that can provide information to facilitate the diagnosis of various diseases, including cancer and dementia, according to the nucleic acids (RNA and DNA) and proteins contained within them or expressed on their surface. However, current methods of EV detection require complex, labor- and time-intensive processes. Recently, using microflow-type light-induced acceleration system (LAC-SYS), we have successfully detected attogram-level target proteins without any pretreatment after only several minutes of laser irradiation [T. Iida, et al., Commun. Biol. 2022]. In this contribution, based on such a micrflow-type LAC-SYS, we have tried rapid, sensitive, and specific detection of nanoscale EVs. Remarkably, we revealed that 10^3–10^4 nanoscaleEVs can be selectively detected from diverse cancer cells (colorectal cancer HCT116 cells and lung cancer A549 cells) with only a 500-nL liquid sample within 5 min using light-induced acceleration of specific binding with antibody-modified probe microparticles (MPs) under controlled microflow [K. Fujiwara, et al., Nanoscale Horizons 2023]. Also, it has been clarified that the detection range of nanoscale EVs can be controlled simply by changing the action range of the optical force by defocusing the laser beam, which is consistent with the theoretical calculations of binding dynamics under optical force and pressure-driven flow. Our obtained results will provide the benchmark for the ultrafast sensitive quantitative measurement of biological nanoparticles, which can enable innovative high-throughput bioanalysis of cell-to-cell communication and facilitate the early diagnosis of various types of diseases such as cancer, dementia, and microbial infections.

Keywords: Biomedical optics; Optical force; Microfluidics; Bio-nanomaterials

Topic: GT2: Biomedical Optics and Imaging
Abstract No: 15572

Robust acquisition-reduced iterative structured illumination microscopy

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Content

Structured illumination microscopy (SIM) holds promising prospects in bioscience thanks to the advantages of fast imaging speed and low photodamage. However, conventional SIM reconstruction concentrates on minimum of 9 consecutive exposures required linear regression solutions predicated on computationally cumbersome parameter estimates to achieve anisotropic resolution doubling, which still compromises imaging speed and exacerbates photodamage, posing a significant challenge for dynamic imaging of live cells. In this work, we propose a robust acquisition-reduced iterative SIM reconstruction algorithm (we called RISIM). RISIM jointly solves the parameter estimation and image reconstruction tasks through only three acquisitions, and iteratively optimizes artifact-free, high-quality super-resolution target with better global performance starting from a noise-filtered initial estimate without complex artificial parameter adjustment. We demonstrate that RISIM can perform robust super-resolution reconstruction in complex fluorescence imaging scenarios with low signal-to-noise ratio and achieve superior imaging quality than conventional regression reconstruction methods.

Keywords: Structured illumination microscopy, super-resolution, acquisition-reduced

Topic: GT2: Biomedical Optics and Imaging
Abstract No: 15586

Opto-acousto-fluidic microplatform for label-free high-throughput detection and sorting of microalgal cells

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Content

Microalgae play a crucial role in the global carbon cycle by efficiently converting carbon dioxide into valuable macromolecules. Among these microalgae species, *Haematococcus pluvialis* (*H. pluvialis*) stands out as a remarkable natural source of astaxanthin – an invaluable antioxidant, anti-inflammatory and anti-apoptotic compound. These inherent advantages underscore astaxanthin's high commercial value in pharmaceuticals, cosmetics, and nutrition industries. However, both intrinsic genetic traits and external cultivation conditions significantly influence the yield of astaxanthin. The low productivity and extraction pose technological and economic obstacles within the industry. Thus, accurate detection of astaxanthin in *H. pluvialis* is of paramount importance for the assessment of factors affecting bio-compound accumulation and identification of astaxanthin-rich *H. pluvialis cells*. Via label-free monitoring of light-absorbing molecular-induced ultrasonic signals, a novel photoacoustic microscopy is proposed for the visualization of astaxanthin content and distribution within *H. pluvialis* cells. Furthermore, it can serve as an on-chip image-based flow cytometry for high-throughput, real-time measurements. The results closely align with spectrophotometer and reveal the heterogeneity of astaxanthin distribution at the single-cell level. A dual-mode solenoid valve-pump is integrated for noninvasive screening of astaxanthin-rich microalgae. *H. pluvialis* cells with astaxanthin accumulation greater than 30 μm in diameter are successfully sorted, with a significant reduction of fluid response time by 50% during rise and 40-fold in recovery. The opto-acoustic-fluidic microplatform enables label-free high-throughput detection, analysis and sorting of microalgae to enhance the extraction efficiency and purity of astaxanthin. This system also holds the potential for screening highly capable mutants for biofuel and other biomaterials.

Keywords: Microalgal cell sorting; astaxanthin detection; photoacoustic microscopic imaging; flow cytometry

Topic: GT2: Biomedical Optics and Imaging
Abstract No: 15656

Upconversion Multimodality super resolution microscopy

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Content

UCNPs represent an entirely new class of multiphoton probes that rely on high densities of multiphoton emitters in small particles. Each particle contains thousands of codoped lanthanide ions that form a network of photon sensitizers and activators, which upconverts near-infrared photons into visible light. Unlike other multiphoton processes, UCNPs have a large number of intermediate excited states that can absorb low-energy photons which are then converted into high-energy photons. Upconversion nanoparticles are highly controllable during the synthesizing process, e.g. sizes ranging from a few nanometers to 100 nanometers. Due to the advantages of narrow emission spectra, high chemical stability, low toxicity, long luminescence lifetime, and high resistance to photo-quenching and photobleaching of UCNPs and the large anti-Stokes spectral separation between excitation and emission, UCNPs have served as probes for background-free and photostable bioimaging. Taking advantage of the nonlinear photo-response of rare earth elements inside UCNPs. Here, we reported a series of new modes of super-resolution technologies for bio-photonics applications.

Keywords: Upconversion nanoparticles; super resolution imging;

Topic: GT3: Computer Vision Techniques
Abstract No: 15617

Active thermal marker using thermal images of heated areas with visible semiconductor laser

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Content

In situations where the object being captured or the camera itself is in motion, object tracking using conventional attached markers or detailed textures is useful to keep capture the object with high accuracy; however, tracking accuracy has been degraded in situations where texture features are scarce or where it is difficult to attach markers. Therefore, in this study, the temperature rise corresponding to the laser irradiation time to the object is detected by a thermal camera, and the points where the temperature reaches or exceeds a threshold value after the laser irradiation ends are used as markers. After the temperature drops, laser irradiation is performed again to repeatedly generate markers. Furthermore, by controlling the irradiation point with a 2-axis galvanometer mirror, a marker that can code arbitrary shapes and information can be generated on a 2-dimensional plane. In our experiments, we irradiated a red semiconductor laser onto black paper, and found that an irradiation time of 10 ms was the most efficient in terms of heat dissipation time, enabling the simultaneous generation of up to 33 markers. As a result, it was found that it is possible to draw distinguishable characters and graphics such as lines and circles by continuous drawing. Future plans include application to non-paper based on additional physical property investigations and actual tracking applications.

Keywords: Active thermal marker; object tracking; thermal camera; laser heating; galvanometer mirror

Topic: GT3: Computer Vision Techniques
Abstract No: 15641

Spinning disk confocal microscopy image stitching

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Content

Spinning disk confocal microscopy can be used as an area-based chromatic solution for wafer inspection. A specimen is partitioned into tiles arranged in rows and columns. The scanned images for all the tiles are stitched together to cover the whole specimen. However, In the spinning disk confocal microscopy system, precise synchronization between the camera exposure and disk rotation is crucial for obtaining high-quality images. When this synchronization is not properly configured, it gives rise to "streaking artifacts" which poses significant challenges to the stitching application. As the artifacts introduce irregularities in the captured images, the stitching algorithm may struggle to identify the correct alignment between adjacent tiles. The optical system's vignetting effect worsens the situation. As the brightness decreases towards the edges of the images due to vignetting, additional complexities are introduced when attempting to stitch the tiles together seamlessly. In this paper, we investigate an approach to accomplish the stitching of such images, combining feature-based matching, transformation estimation, and image blending to achieve seamless stitching results.

First the SIFT algorithm is employed to extract features, which are matched by a Fast Library for FLANN matcher. Then RANSAC algorithm is used to determine the transformation matrix. Lastly a weighted linear blending method is applied to blend the overlapping areas of the adjacent tiles.

Experimental evaluations demonstrate that the proposed solution is practical and efficient. Furthermore, its applicability extends beyond wafer inspection, making it a valuable tool for diverse fields requiring image stitching capabilities.

Keywords: image stitching, SIFT, FLANN, RANSAC, linear blending, spinning disk confocal microscopy

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15475

Single-shot microscopic autofocus focusing on image detail features

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Content

Autofocus plays an important role in microscopic imaging. As an extension of image-based methods, learning-based methods make real-time autofocus possible. The learning-based methods use the neural network model to establish a complex relationship between image edge and texture features and defocus distance, thereby achieving focusing. Therefore, the focusing accuracy of these methods depend partly on the ability of the network model to extract image edge and texture features. In this paper, an improved neural network model was proposed, which predicts the defocus distance from a single natural image, to improve the model's ability to extract image detail features. Furthermore, a realistic dataset of sufficient size was made to train all models. The experiment demonstrated that the proposed model had better focusing performance, and had stronger ability to extract edge and texture features. The dataset is publicly available.

Keywords: autofocus; microscope; natural image; learning-based; single-shot

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15479

Real-time polarimetric de-scattering imaging technology: from thread framework to algorithm optimization and underwater demonstration

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Content

Polarization is a key and basic attribute of light wave besides the amplitude, the frequency or wavelength, and the phase. And polarimetric imaging, as a novel optical imaging approach which is based on measuring or detecting the polarimetric characteristics of the reflected light from the target, has been widely used to perform some special advantages in object identification and segmentation, material and its surface defect inspection, biological tissue pathological changes diagnosis, etc. As usual, underwater images acquired in scattering environments are generally of poor quality because of the attenuation and backscattering of light when it passes through water with scattering particles. And polarimetric de-scattering methods can be used to significantly enhance the imaging quality in such a so-called turbid water. However, due to the complexity of polarimetric de-scattering algorithms, it is hard to achieve real-time de-scattering output from a polarimetric camera. In this talk, in order to efficiently increase the computational efficiency, the polarimetric de-scattering algorithm is optimized and a multi-threading framework is developed that enables the algorithm to run in real-time on ordinary laptops for the same polarimetric camera. We demonstrate the imaging performance by using the underwater polarimetric de-scattering system we proposed. We analyze the algorithm under different scattering conditions and discuss its optimal parameters. We find that there is a significant increase in the number of SIFT (i.e., scale invariant feature transform) feature points extracted from the processed image compared to the original image, showing that our system has potential applications in pattern recognition, computer vision, etc.

Keywords: polarimetric imaging; underwater de-scattering; real-time image processing

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15485

High robust spatio-temporal wavefront prediction in adaptive optics via a mixed graph neural network

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Content

Due to the response time of hardware, time-delay problem is a critical and non-ignorable problem of adaptive optics (AO) systems. It will result in significant wavefront correction errors while turbulence changes severely or system responses slowly. Predictive AO is proposed to alleviate the time-delay problem for accurate and stable corrections in the real time-varying atmosphere. However, the existing prediction approaches either lack the ability to extract non-linear temporal features, or overlook the authenticity of spatial features, leading to poor performance in generalization. Here we propose a mixed graph neural network (MGNN) for spatio-temporal wavefront prediction. MGNN introduces the Zernike polynomial for model enhancement and takes its inherent covariance matrix as physical constraints. It takes advantage of convolutional and graph convolutional layers for temporal feature catch and spatial feature analysis, respectively. Especially, the graph constraints from covariance matrix and the weight learning of transformation matrix can establish a realistic internal spatial pattern from limited data. Furthermore, its prediction accuracy and robustness to varying unfamiliar turbulences, including the generalization from simulation to experiment, are all discussed and verified. By comparing with two conventional methods, the outperformance of proposed method is demonstrated by root mean square error (RMS) of temporal turbulence. With the prediction of MGNN, the mean and standard deviation values of RMS in conventional AO are reduced by 54.2% and 58.6% at most, respectively. The stable prediction performance makes it suitable for wavefront predictive correction in astronomical observation, laser communication, and microscopic imaging.

Keywords: Predictive adaptive optics, graph neural network, Zernike model enhancement, covariance matrix, robust generalization.

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15488

Polarization demosaicking algorithm based on polarization channels correlation

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Content

Utilizing four polarization channels to recover the image, Division of Focal Plane(DoFP) polarimeter recently has shown great promise because of its real-time imaging and simple structure. However, sparsity-sampling of DoFP limits the quality of image recovery, thus the correlation of different channels is required as supplement. Unlike spectral correlation coming from the overlap of different bands that have been intensively investigated, the correlation between polarization channels is hard to define. In this work, the Degree of Linear Polarization(DoLP) of incident light is carried into the Pearson Correlation Coefficient(PCC) formula as affecting factor of correlation between different polarization channels, which demonstrates a high correlation in low DoLP zones and a low correlation in high DoLP zones. The relationship between PCC and DoLP is then carried into demosaicking algorithm as correction factor between different polarization channels. With this correction factor and gradient in different polarization channels, the gradient from unknown points to its surrounding area can be calculated and make interpolation more accurate. Meanwhile, a direction criterion based on polarization difference is incorporated into it to recover more accurate boundary features. The final interpolated image shows effective improvements in evaluation metrics based on real images and has a relatively shorter computation time when compared with other demosaicking algorithms on different databases. As a channel-correlated-interpolation algorithm, the algorithm combines the DoLP of light with the polarization-correlation to better recover image details.

Keywords: Demosaicking; Polarization; Polarization correlation

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15505

A Two-Stage Deep Learning Method for Foreign Object Detection and Localization

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Content

Foreign object detection and localization is of critical importance in various real-world scenarios. For example, a foreign object in an automatic assembly line could result in severe dangers in a robot operating workplace. In this paper, we propose a two-stage deep learning method to identify and localize foreign objects in a working environment.

The proposed method includes two major stages, i.e., detection and localization. In the detection stage, an advanced anomaly detection model, i.e., PaDiM (Patch Distribution Modelling) model, is first used to identify potential unknown objects. The model makes use of a pre-trained CNN model for patch embedding and of multivariate Gaussian distribution to concurrently detect and localize unknown objects in images. However, the unknown objects detected by PaDiM usually include normal classes. Subsequently, we use the working environment data to train a YOLO model, which has super performance on object detection and segmentation, to filter out the true positives in the potential anomalies.

In the localization stage, we first use K-Means++ to cluster a heatmap generated from PaDiM into different regions and extract keypoints with highest activation scores. Next, we utilize advanced SAM (Segment Anything Model) model with the extracted keypoints, to accurately segment and localize the foreign objects.

We have conducted experiments on both public datasets and our own datasets and promising results have been achieved using the proposed two-stage deep learning solution. In addition, the developed models can be well-adapted to various scenarios in manufacturing automation.

Keywords: Foreign object localization; Object detection and segmentation; Anomaly detection; K-Means++; Convolutional neural network

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15511

Image-based wavefront sensing and correction for atmospheric turbulence by using deep reinforcement learning

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Content

We have developed a deep reinforcement learning (DRL) framework for atmospheric turbulence wavefront sensing and correction by imaging extended targets through atmospheric turbulence. The correction of the atmospheric turbulence is modeled as a Markov decision process. The states of the DRL framework are the distorted intensity images, the actions are the Zernike coefficients which are loaded on a deformable mirror (DM), and the rewards are the Strehl ratios. In the DRL framework, a deep neural network (U-net) is used to reconstruct the turbulence phase from the distorted intensity images, and the deep neural network is optimized using the deep deterministic policy gradient (DDPG) algorithm. The convergence of the DDPG algorithm for wavefront reconstruction of the atmospheric turbulence is systematically analyzed and the results show that the convergence is controlled by the learning rates and discount factor and depends on the weight parameters of the U-net. A simulated atmospheric turbulence imaging system is built to test the performance of the DRL framework. During an atmospheric turbulence correction cycle, the DRL framework acquires a distorted intensity image and reconstructs the corresponding phase, and loads it onto the DM to obtain the reward from the environment. The DDPG algorithm then updates the weights of the U-net after accumulating a certain number of rewards. By choosing the appropriate initial parameters of the U-net, the learning rates, and the discount factor, the DRL framework can converge on multiple targets by online optimization.

Keywords: Wavefront sensing; Applied Optics; Deep reinforcement learning

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15628

Microscopic Spectra Measurement Based on Coherence Scanning Interferometry

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Content

Microscopic spectral measurement finds diverse applications across biomedicine, material science, food safety, and semiconductor research. Fourier transform infrared spectroscopy (FTIR) is a widely used method for spectral measurement. Despite the conceptual similarity of coherence scanning interferometry (CSI) to FTIR, the latter is typically only suitable for samples with flat and smooth surfaces. CSI can measure complex surfaces and it seems possible to obtain spectral information from CSI fringes through a simple Fourier transform. However, due to factors like large illumination angles, sample surface scattering and diffraction limit of the optical system, the spectrum of CSI signal does not provide an accurate measure of the spectrum of the sample material. To address these challenges, we have extended the 3D linear theory of CSI to take into account the “colors”, describing the spectral response characteristics of CSI to a complex surface. We have constructed pseudo-inverse filters based on a prior information of the 3D transfer function of a CSI system within the desired spectral range. These filters are then applied to CSI fringe data to reconstruct the reflection spectra of the sample. Through simulations and experiments, we have preliminarily validated the feasibility of the proposed method. This approach showcases advantages such as spatial resolution approaching diffraction limits, high light utilization efficiency, and high data throughput. Further exploration is underway to advance this method.

Keywords: Microscopic spectra measurement; Coherence Scanning interferometry; Three-dimensional transfer function; Pseudo inverse filter

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15631

Design of Point Cloud Data Structures for Efficient Processing of Large-Scale Point Clouds

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Content

Existing three-dimensional scanning techniques enable the acquisition of dense point clouds representing the surface of the scanned object. However, the voluminous nature of unordered point cloud data leads to extended data processing times, necessitating the utilization of specific data structures for the management of large-scale point clouds. Addressing the performance degradation issue of prevalent point cloud data structures when dealing with a large quantity of points, this paper initiates a comparative analysis of common point cloud data structures, encompassing grid-based, quadtree, and k-d tree (k-dimensional tree) indexing methods. Through theoretical derivations, an examination of the time complexities of various data structures is undertaken. Building on this theoretical foundation, an empirical quantitative assessment of the real-world performance of distinct data structures is executed. Leveraging the insights gained from these analyses, this study further capitalizes on the inherent shape characteristics of empirically acquired point cloud data to introduce a novel three-tier hybrid indexed point cloud data structure, accompanied by its corresponding algorithmic functionalities. This innovative structure amalgamates grid-based, quadtree, and k-d tree indexing strategies. Empirical findings demonstrate that, when applied to large-scale point clouds, the proposed three-tier hybrid indexed data structure exhibits enhanced indexing establishment speed and neighborhood search velocity compared to conventional algorithms. Thus, this work establishes a foundational data structure support for subsequent processing and application of large-scale point cloud data.

Keywords: Large-scale Point Clouds, Point Cloud Data Structures, Point Cloud Data Processing, 3D Measurement

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15636

Research on Dimension Measurement Based on 3D Point Cloud

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Content

In the manufacturing industry, the high-precision and high-efficiency dimension measurement of the large components is an important guarantee to improve product quality and production efficiency, but the traditional contact measurement method is low efficiency, poor accuracy, time consuming and vulnerable to human factors interference, has been unable to meet the requirements of rapid and accurate measurement. To solve this problem, based on the three-dimensional point cloud data of large components, this paper studies the geometric feature extraction and dimension measurement methods of components. The 3D point clouds of components are preprocessed by establishing topological relationship, estimating surface normal vector and point clouds filtering for noise reduction. Geometric features of preprocessed point clouds are extracted, including point clouds with straight line features such as side edges and point clouds with circular arc features. The specific steps include extracting key planes by RANSAC, extracting edges of planes based on normal vector estimation, extracting bus bars at different positions by three-dimensional rigid body transformation, retaining point clouds with geometric features, and dividing point clouds by European clustering. After that, the extracted point clouds with geometric features are synthesized into straight lines or circles to measure straightness and roundness. Besides, a method is proposed to search adjacent points on the linear point clouds in order to measure arc length and analyze error sources and accuracy. The experimental results show that the measurement method proposed in this paper can achieve high precision dimension measurement of the components.

Keywords: 3D point cloud; Dimension measurement; Geometric features extraction

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15664

CycleSR: Unsupervised Learning for 3D fingerprint Super-Resolution

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Content

Fringe Projection Profilometry (FPP) is a non-contact optical 3D measurement technique used to capture the 3D shape and surface characteristics of objects. One of the application area is to capture the contactless 3D fingerprints. Fingerprints need high resolution cameras to capture clear ridge and valley which may not be satisfied in practical applications. Low-resolution fringe patterns lead to unclear valleys and ridges in the reconstructed contactless 3D fingerprints. To solve this problem, we propose an unsupervised super-resolution (SR) method that only utilizes low-resolution fringe patterns. Our approach combines a two-loop generative adversarial network. In the forward loop, a binarized interpolation loss function is designed to ensure that the upsampling generator preserves ridge and valley details. In the backward loop, the discriminator ensures that the fringe patterns produced by the downsampled generator are both repeatable and similar to the original fringe patterns. Finally, the fringe patterns are reconstructed to obtain 3D fingerprints. Experimental results demonstrate the advantages of our proposed method.

Keywords: Fringe pattern, Super-resolution, Generative adversarial network, 3D reconstruction

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15682

Predictions gender of Moina by using digital holography and deep learning

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Content

Digital holography is an imaging technique that involves capturing images on a digital camera, using these recorded images to generate new holographic images through computer programs. In this study, we utilized a digital holographic microscope (DHM), capable of recording particles ranging in size from micrometers to nanometers. The DHM was employed to capture images of Moina, allowing us to observe their shapes. Given that Moina has a size in the millimeter range, determining their gender is challenging for the human eye. To address this, our study employs deep learning to predict the gender of Moina based on images obtained from the DHM. Moving forward, our research aims to explore the movement patterns of Moina.

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15684

Hyperspectral Anomaly Detection Based on Background Purification and Spectral Feature Extraction

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Content

Hyperspectral image (HSI) anomaly detection has gained great attention has gained great attention in remote sensing, for it does not require a priori information. Accurate discrimination is made by analysing the difference between the anomalies and the background pixels. Many works have been proposed to reconstruct the background and eliminate the anomalies from original scene. However, bands in hyperspectral images are usually highly correlated with each other, bringing a lot of redundant information. The redundant information not only burdens the detection process, but also weakens the difference between the background and anomalies. This paper introduces a background purification and feature extraction strategy to enhance the difference between anomalies and background pixels. To be specific, the domain transformation extracts discriminative sample features. The row-constrained low-rank sparse matrix decomposition is utilised to obtain purer low-rank background matrices, and to highlight the anomalies. Highly representative and low redundancy bands are selected in local regions. Finally, the local region is detected by RX and the map is obtained by domain-valued normalisation of the local results. Experiments results and data analysis show that the proposed method can suppress the background well, and can also make full use of the spectral information to achieve acceptable detection accuracy.

Keywords: hyperspectral image (HSI), anomaly detection (AD), iterative band selection, low-rank sparse matrix decomposition

Topic: GT6: Image Processing and Deep Learning
Abstract No: 15685

Remote sensing image target detection via Gaussian distance loss

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Content

Neural networks have found extensive applications in the field of object detection, yielding excellent results. Remote sensing images, compared to regular images, exhibit characteristics such as a higher prevalence of small objects, complex backgrounds, variable angles, and imbalanced sample quantities. When traditional neural networks are used for object detection in remote sensing images, they often perform poorly on categories with small objects and fewer samples. Therefore, this paper introduces a neural network optimization approach targeting the issues of small objects and sample quantity imbalance. Instead of using the Intersection over Union (IoU) loss, a gaussian distribution distance loss is proposed, allowing the network to learn even when the predicted bounding boxes do not overlap with the ground truth boxes, thereby improving the detection of small objects. To address the imbalanced dataset issue, adaptive learning weights are adjusted, enabling the network to extract more features when dealing with a limited number of samples. Experimental results demonstrate that both of these methods enhance the network's detection performance, and when compared to other mainstream networks, this approach exhibits certain advantages.

Keywords: Remote Sensing, target detection, Gaussian distribution distance

Topic: GT9: Non-Destructive Testing and Inspection
Abstract No: 15535

Improved Video Motion Magnification Method Assisted by Digital Image Correlation

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Content

Video Motion Magnification (VMM) allows us to observe subtle changes in objects, and important information often lurks in subtle changes. Therefore, VMM technology has been widely concerned in various fields. However, improper parameter settings in traditional algorithms often lead to image artifacts and noise, particularly when dealing with weak motion. This paper presents an improved VMM method that leverages the Digital Image Correlation (DIC) technique to address this limitation. By analyzing the dominant motion frequencies based on DIC-measured image displacement results, the proposed method sets the parameters of the VMM time domain filter accordingly. This approach achieves motion magnification in videos while preserving image details and minimizing noticeable artifacts. The results obtained from simulation experiments conducted on an indoor precision displacement platform and vibration measurements conducted on an outdoor bridge substantiate that the proposed method eliminates the requirement for repetitive manual parameter adjustment through trial and error. It yields clear and magnified motion videos while enabling accurate measurement of small-scale motions.

Keywords: Video motion magnification, Digital image correlation, Time domain filter, Displacement measurement

Topic: GT9: Non-Destructive Testing and Inspection
Abstract No: 15538

X-Ray computed tomography based high-accuracy analysis for the compressive properties of thin shell lattice structures: effect of geometric defects

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Content

Micro laser powder bed fusion (µLPBF) is an additive manufacturing process enabling the fabrication of thin-walled metallic shell lattices with wall thicknesses less than 100 µm, greatly facilitating the design of lightweight, stiff, and strong structural components. However, as the wall thicknesses approach the printing resolution, µLPBF process is likely to introduce geometric defects, which can significantly influence the mechanical properties of thin shell lattices.

To quantify the process-induced geometric defects and to understand the influences of the geometric defects on the mechanical properties of thin shell lattices, we propose a micro X-ray computed tomography (XCT) based finite element (FE) modelling methodology, which is validated for Primitive-type shell lattices fabricated by µLPBF in stainless steel. Four types of geometric defects, namely thickness variations, through-thickness defects (holes), surface waviness and roughness, are incorporated into the shell element-based FE models. Numerical and experimental compression test results show that the XCT-based defect-informed simulation approach provides significantly improved prediction accuracy compared to the ideal geometry model in terms of stiffness, peak stress, plateau stress and densification behaviour. Defect sensitivity analyses highlight that surface roughness and thickness variations lead to prominent impact on the reduction of both linear and nonlinear mechanical properties. Furthermore, we propose wall thickness deviation prediction and compensation methods to understand the major sources of thickness deviations and to mitigate this defect. Experimental results show that the thickness deviations of a Primitive-type shell lattice with an as-designed thickness of 135 µm can be reduced to less than 15 µm after compensation.

Keywords: X-Ray computed tomography; Thin shell lattices; Geometric defects; Micro laser powder bed fusion; Mechanical properties

Topic: GT9: Non-Destructive Testing and Inspection
Abstract No: 15549

Feasibility of in-situ health monitoring for composite structure with embedded piezoelectric sensor networks

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Content

Continuous Inspection and maintenance of high performing modern aircraft composite structures are essential to ensure the safety and efficiency of the aviation industry. Unlike conventional metals, the damage of fibre-reinforced polymer matrix composite materials that are commonly used in aviation components is relatively difficult to detect, given the various micro-constituents present. Especially, carbon fiber-reinforced polymer and glass fiber-reinforced polymer laminate can produce no-visible surface damage while sustaining internal delamination and fiber failures upon experiencing low-velocity impact forces. Barely visible impact damage (BVID) is one of important damages that is tedious to detect with non-destructive methods as the damage's location and level unknown to the operator until detection occurs. Therefore, structural health monitoring (SHM) is an active system that provides constant surveillance of vital composite structural conditions. In this work, piezoelectric based sensors are embedded into composite laminate during the layup sequencing with electrical cables for voltage detection under low-speed impact loading. Experiments were conducted with a set of sensors at varied impact locations. The measured signals are analysed for their intensity with reference to location. A machine learning (ML) model is developed to provide a predictive method for SHM of the composite structure. Besides, mechanical tests are conducted to prove the compatibility of the embedded sensors in the host structure. The result from this study aims to develop a novel solution for a jet engine's smart skin to increase the safety of composite components, assist repair technicians in reducing aircraft-on-ground time, as well as to enable the predictive maintenance tool.

Keywords: Piezoelectric sensors; structural health monitoring; barely visible impact damage; polymer matrix composite laminates; machine learning model.

Topic: GT9: Non-Destructive Testing and Inspection
Abstract No: 15645

Characterization of X-ray scintillation film

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Content

An alternative to direct X-ray detection, scintillation is a form of indirect detection that convert X-rays to visible light and subsequently electric signals. Scintillators refer to materials that exhibit luminescence when excited by ionizing radiation. Currently, commercial X-ray scintillator films are typically manufactured using gadolinium oxysulfide (Gd_2O_2S) or cesium iodide (CsI). However, inorganic perovskite nanoparticles are emerging scintillation materials that possess high light-conversion efficiency and tunable luminous properties, making them a strong alternative to commercial scintillators that should be explored. An optical imaging prototype was developed to evaluate the performance of ligand-encapsulated inorganic perovskite nanoparticles. Inorganic perovskite nanoparticle film samples are prepared using various methods and exposed to 225kV and 450kV X-ray sources. Using the optical system's image processing software, the samples are assessed in terms of brightness and resolution and benchmarked against a commercial sample. Modulation transfer function (MTF) measurement is used to determine the sample's effective resolution. During the experiment, some challenges include reducing image noise and improving the accuracy of the MTF measurement given the limited contrast arising from the low-light conditions. The experimental results find that inorganic perovskite nanoparticles are a viable alternative to commercial scintillators but require further finetuning in the production methods to achieve similar effective brightness and resolution.

Keywords: X-ray; scintillation; optical imaging

Topic: GT10: Optical Component and System Simulation
Abstract No: 15548

New Virtual Model as A Built-in Thin Lens Component of Optical Software to Balance Component Aberrations Between Different Zoom Positions of Optical Lenses

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Content

Solving conceptual thin-lens components with balanced primary aberrations among different zoom positions is essential for lens design from scratch. The primary aberrations include five monochromatic aberrations named the spherical aberration S1, coma S2, astigmatism S3, field curvature S4, distortion S5, as well as two chromatic aberrations named the longitudinal chromatic aberration CL and transverse chromatic aberration CT. The optical theorem shows thin components comprise only three independent aberrations, i.e., S1, central coma S2C, and CL. The aberrations S2, S3, and S5 are functions of S1 and S2C, while CT depends on CL. Optical aberrations vary from zoom positions, and we have derived the variation algorithms of S1 and S2C, helping find balanced aberrations [Appl. Opt. 55. 10363 (2016)]. The paper presents a practical method for solving the independent aberrations of conceptual thin-lens components by using the optimization process of Code V (a famous optical design program) to approach specific system aberration targets. For this purpose, a concept component is modeled using one Code V's lens module and one zero-diffraction-order hologram. The hologram parameters provide virtual spaces for storing the reference data of incident marginal and chief rays, spherical aberration S1, central coma S2C, and longitudinal chromatic aberration CL without affecting the paraxial ray tracing. Those reference data are used to evaluate the aberrations at other zoom positions. The model helps investigate the properties of lenses and solve the balanced aberrations. An illustration example of solving a zoom lens is given to demonstrate the usage of the method.

Keywords: Lens design; optical aberration; aberration variation; zoom lens

Topic: GT11: Optical Functional Materials and Devices
Abstract No: 15569

Optical Imaging and Optical Manipulation Based on Microdroplets

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Content

With the development of nanoscience and nanotechnology, the observation of the microscopic world has gradually entered the nanoscale. For better observation and detect the signal from nano samples, the research orientations of the optical system are also now moving towards performing at high imaging resolution, sensitivity, and integration. In recent years, the transparent dielectric microsphere has been used as an auxiliary lens by researchers to achieve super-resolution optical focusing and imaging. It can be quickly integrated with various optical systems, due to the simple structure of the microsphere, which makes the microsphere-assisted technique show great application prospects in laser processing, information storage, and biological imaging. However, the microspheres used in the existing research are often made of solid materials. The tunability of the optical properties of the microlens is difficult to achieve in a solid microsphere with a stable solid structure, and the low biocompatibility and biodegradability of a solid microsphere limit its application in biological research. Inspired by the convergence phenomenon of dewdrops on sunlight in nature, this paper proposes to use soft materials such as droplets and natural biological components to prepare microlens to meet the application requirements of adjustable focal length and high biocompatibility. In this paper, the fabrication methods of droplet microlenses of artificial and natural biological materials, their basic optical properties, and their applications in optics (imaging and detection) are explored. And the optical manipulation technique is employed to adjust the shape and position of microdroplets with high spatiotemporal precision.

Keywords: Optical manipulation, Optical imaging, Droplet microlens, Bio-microlens, Optothermal droplet.

Topic: GT12: Optical Measurement Methods
Abstract No: 15491

Internal defect detection method based on dual-channel speckle interferometry

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Content

A novel dual-channel speckle interferometry based on a monochromatic camera is proposed to quantitatively characterize internal defects in materials. The sensor of the monochromatic camera is divided into two inde-pendent and simultaneous imaging channels by integrating dual-biprism and dichroic filters. The combination of electronic speckle pattern interferometry and digital shearography allows for the simultaneous measurement of out-of-plane displacement and slope. The [4+1] phase-shifting algorithm is employed to dynamically detect of the sequential phase. The effectiveness and accuracy of the proposed method are verified by testing a centre- loaded circular plate. Furthermore, the developed system performs non-destructive testing on a thin metallic plate with internal defects. The experimental results show that the proposed method can successfully localize and detect internal defects.

Keywords: Dual-channel speckle interferometry; Simultaneous out-of-plane displacement and slope measurement; Internal defects localization; [4+1] phase-shifting algorithm.

Topic: GT12: Optical Measurement Methods
Abstract No: 15496

A Novel Method to Parallel Beam Generation for Roll Angle Measurement

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Content

The assessment of geometric errors of linear guides is important for determining machine tool precision. Detection of roll angle is more challenging than other geometric errors. A brand-new method to generate parallel beams for roll angle measurement is proposed in this paper. Two beams with stable parallelism are produced using a laser diode (LD), a beam splitter (BS), and two corner cube reflectors (CCRs). The parallelism of the two beams is determined by the angular error of the CCRs, which is not affected by installation. The theoretical expression of beam parallelism is demonstrated and a self-developed 3-DOF measurement system is used to validate the effectiveness. The experimental results show that the 3-DOF measurement system has a beam parallelism of 5.90 ″, a straightness measuring range of ± 400 μm and a roll angle measuring range of ± 300 ″. The generated parallel beams have the advantages of easy assembly and stable parallelism, which can be developed in multi degree of freedom measurement systems.

Keywords: Geometric errors; Roll error; Machine tool; Multiple-degree-of-freedom system

Topic: GT12: Optical Measurement Methods
Abstract No: 15502

Some recent advances in mirror-assisted multi-view digital image correlation

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Content

Mirror-assisted multi-view digital image correlation (MV-DIC) is a sophisticated DIC technique suitable for panoramic/dual-surface kinematic field measurements of regular-sized specimens. To further simplify the technology and enhance its versatility in specific scenarios, three critical aspects of mirror-assisted MV-DIC, including system design, speckle pattern fabrication, and reflection transformation calibration have been optimized. Regarding system design, a single-camera mirror-assisted MV-DIC method was proposed by using a customized four-mirror adapter. With the four-mirror adapter, the camera can capture the stereo images of the real surface and virtual surfaces reflected by the planar mirrors placed behind the test object. A smartphone camera and an industrial camera were respectively used to construct single-camera mirror-assisted MV-DIC systems. Regarding speckle pattern fabrication, to leverage the advantages of fluorescent DIC in mirror-assisted MV-DIC, a designable, rapid and repeatable fluorescent speckle pattern fabrication method using a handheld inkjet printer was proposed. With the aid of quick-drying fluorescent ink cartridge, the handheld inkjet printer is capable of printing numerically generated digital speckle patterns on test sample surfaces, which allows designable, rapid and repeatable fluorescent speckle pattern fabrication in few seconds. Regarding reflection transformation calibration, as a simple fabrication method has been proposed, to fully utilize the camera's spatial resolution and simplify the calibration processes, we propose to use fluorescent speckle patterns fabricated on the mirrors to calibrate their reflection transformation matrices. Excellent performances of all the three methods have been confirmed with real DIC experiments.

Keywords: mirror-assisted MV-DIC; system design; speckle pattern fabrication; reflection transformation calibration

Topic: GT12: Optical Measurement Methods
Abstract No: 15514

Heat haze neutralization on high-temperature digital image correlation measurements via deep learning

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Content

Digital image correlation (DIC) techniques have become the fundamental experimental technique for deformation measurements of structures and materials at high temperatures. However, caused by the uneven distribution of temperature and refractive index, heat haze, as a key problem for high-temperature DIC measurement, can lead to distinct distortions to the captured image and significantly influence the measurement accuracy. Inspired by an atmospheric turbulence neutralization neural network called TSR-WGAN, in this work, a deep learning-based method to neutralize the heat haze effect on high-temperature DIC measurements is proposed. Specifically, the original distorted speckle images captured in the experiment are inputted into the TSR-WGAN network twice to obtain the corrected speckle images. Then, by employing the conventional subset-based DIC, displacement and strain fields of these corrected speckle images can be determined with mitigated heatwave distortions. The experimental results clearly show the effectiveness and robustness of the proposed method in heat haze correction. One of the experiments shows that the displacement error caused by the heatwave distortion is reduced by approximately an order of magnitude in the *u* direction and by a factor of five in the *v* direction. The proposed method provides an effective tool for neutralizing the impact of heat haze on the high-temperature DIC measurements.

Keywords: High temperature deformation; Digital image correlation; Deep learning; Heat haze

Topic: GT12: Optical Measurement Methods
Abstract No: 15515

Using three-dimensional electronic speckle pattern interferometry to study Quasi-static response of two-dimensional dense granular packings to localized force

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Content

To better unstand the static mechanical response of granular packings to the localized force, three-dimensional electronic speckle pattern interferometry (3D ESPI) is developed for 3D micro displacement measurement. The 3D ESPI system consists of two pair of symmetrical illuminating arrangement with dual-wavelength lights, which were used to independently sense two in-plane deformation components, and one Michelson interferometer-based set illuminating with the other wavelength light, which was utilized to measure out-of-plane deformation. One 3-sensor color camera was employed to grab color speckle interferograms. The micro static rotational displacement or 3D deformation can be simultanously measured by using the 3D ESPI system. The propagation of the contact forces among the grains can be deduced according to the measured displacement. Experiments are performed on two-dimensional cohesionless monodisperse granular packings composed of about 300 acrylic cylinders. The experimental results are in agreement with simulations performed using the discrete element method.

Keywords: 3D electronic speckle pattern interferometry; 3D displacement measurement; Propagating process of contact forces; dense granular packings;

Topic: GT12: Optical Measurement Methods
Abstract No: 15516

Direct strain measurement method based on the correlation of defocused laser speckle pattern

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Content

The structural strain field corresponds to the stress of each point and is an important unavoidable parameter in structural analysis or structural testing. The noncontact optical strain measurement methods are mainly divided into indirect strain measurement methods derived from displacement field differentiation and direct strain measurement methods represented by the digital shearing speckle pattern interferometry. The full-field displacement in the indirect measurement technique is commonly obtained using the electronic speckle pattern interferometry method, the digital image correlation method based on binocular camera or scanning laser doppler vibrometer method, and the differential operation further amplifies the measurement error. This study proposed a strain measurement method based on the defocused laser speckle pattern. In the case of defocus, the laser speckle field is sensitive to only the tilt angle, and the motion mode is the lateral translation of the same speckle field. The strain information can be obtained directly by the correlation calculation of laser speckle patterns before and after deformation. Experiments of the cantilever beam and bilateral clamped plate verified the effectiveness of the proposed method and proved that the proposed method made up for the limitations of the digital image correlation method and digital shearing speckle pattern interferometry method to a certain extent. Appropriate optical parameters and imaging parameters should be selected to ensure the quality of the laser speckle pattern and measurement accuracy.

Keywords: strain measurement; defocus; laser speckle pattern; correlation calculation

Topic: GT12: Optical Measurement Methods
Abstract No: 15524

Uncertainty analysis and optimization design of large-range laser triangulation displacement sensor applied to dynamic object

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Content

The principle of laser triangulation has been widely used in various high-precision measurement due to its advantages of high accuracy, fast response speed and simple structure. However, the laser triangulation method still has some limitations for the measurement of dynamic object, and the accuracy and stability of laser location will be significantly reduced especially when the working range becomes larger. We have carried out the development and performance optimization of a large-range laser triangulation displacement sensor for the application of dynamic object space positioning. First, the measurement uncertainty caused by the variation of optical parameters is analyzed to quantify the error caused by the displacement of dynamic objects, and the initial optical structure parameters are designed according to the analysis results. Secondly, reflectors are added to the optical path structure of traditional laser triangulation system to expand its working range, and the optimal optical structure parameters are determined via ZEMAX simulation. Finally, a space location system is established based on the optimized laser triangulation displacement sensor, and dynamic target is located and measured. The experimental results show that the repeatability of our optimized sensor can realize micrometer-scale measurement after the dynamic target completes a series of actions, and the response speed is higher than 300ms.

Keywords: Large-range laser displacement sensor; Space positioning; Dynamic objects; Uncertainty analysis; Optimization design.

Topic: GT12: Optical Measurement Methods
Abstract No: 15528

Two-dimensional Angle Measurement with Sub-arcsecond Precision and MHz Acquisition Rate Using Heterodyne Interferometry with Optical Frequency Comb

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Content

Precise and rapid measurement of angle plays a critical role in scientific research and advanced industrial manufacturing. For lithography machine, sub-arcsecond angle measurement precision and megahertz-level data refresh rates are required to ensure real-time monitoring and precise adjustment of the position and orientation of motion stage. Moreover, compact and easily installable measurement target is essential for efficient integration of measurement devices and production equipment, ensuring high-quality lithography. In this study, we propose a high precision and rates two-dimensional angle measurement method based on the optical frequency comb (OFC) heterodyne interferometry combined with Grating-Corner-Cube (GCC) sensor which consists of a two-dimensional transmission grating and a corner cube. When the incident beam passes through the GCC sensor, four first-order diffracted beams exit the GCC sensor symmetrically around the zero-order diffracted beam, parallel to the incident beam. By analyzing the phase variation of the heterodyne interference signals generated by ±1st-order diffraction along the x and y axes, pitch and yaw angles can be rapidly and precisely obtained respectively. This method takes full advantage of OFC and the heterodyne interferometry, achieving sub-arcsecond angle measurement precision with a megahertz-level data acquisition rate. Furthermore, the phase spectrum of the zero-order diffracted beam can be utilized for absolute distance measurement along the z-axis based on dual-comb ranging method. Thus, simultaneous high precision and rates three-degree-of-freedom measurement over long stand-off distances is expected to be realized. Such overall performance holds potential applications in various scenarios, including lithography machines, and aircraft-manufacturing processes.

Keywords: optical frequency comb; heterodyne interferometry; angle measurement;

Topic: GT12: Optical Measurement Methods
Abstract No: 15559

Finite strain measurement and stress mapping for thin plate specimen using digital image correlation

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Content

This paper describes a method for measuring the finite strains and subsequent stresses of sheet steel specimens undergoing plastic deformation. A notched sheet specimen made of high-strength steel under a tensile load is observed using stereo vision. The displacement is then determined using stereo digital image correlation. A procedure for estimating the finite strain and corresponding stress from the measured in-plane displacement is presented. First, the deformation gradient tensor is determine. The logarithmic strain component is then determined from the right stretch tensor determined from the deformation gradient tensor. Note that the logarithmic strain determined from the right stretch tensor is used. This is because this strain is related to stress, but not the logarithmic strain determined from the left stretch tensor. Finally, the stresses are evaluated from the strains based on the plasticity theory. The effectiveness of the proposed method is demonstrated. The variation of the stress triaxiality with the progress of the deformation is also shown. Results show that the stresses in the plastically deformed region can be obtained by the proposed method.

Keywords: Digital image correlation; Stereovision; Finite strain; Plastic deformation; Stress triaxiality

Topic: GT12: Optical Measurement Methods
Abstract No: 15584

A Transmission-Reflection Photoelastic Combined Technique for Internal Stress Analysis of Inorganic Flexible Electronic Bilayer Structures

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Content

In recent years, inorganic flexible electronics technology has been widely researched as a promising field that enables semiconductor devices to combine excellent electrical and flexible properties for various electronic applications. However, rigid semiconductor materials are susceptible to fracture during service, leading to functional failure. Therefore, mechanical reliability testing is essential for these devices. Digital photoelasticity is one of the techniques that can be used for stress analysis of semiconductor materials, which is a non-destructive, full-field, real-time experimental method based on stress-optical law. In this paper, a transmission-reflection photoelastic combined technique is proposed for internal stress analysis of inorganic flexible electronic bilayer structures. This technique can achieve non-contact, in-situ, parallel measurement of internal stress fields. A transmission-reflection photoelastic bidirectional combined experimental system is developed. A photoelastic parameter extraction technique for stress decoupling of bilayer structures is introduced. An experimental study on the quantitative characterization of the internal stress field of each layer is conducted for a typical class of inorganic flexible electronic bilayer structures.

Keywords: Photoelasticity; inorganic flexible electronic structures; internal stress; transmission-reflection photoelastic combined technique; phase-shift method

Topic: GT12: Optical Measurement Methods
Abstract No: 15613

Parametric studies of liquid LIBS analysis for agricultural applications

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Content

Laser Induced Breakdown Spectroscopy (LIBS) has received increasing interest in analytical chemistry, biomedical and environmental applications because of its multi-elemental detection capabilities in real-time. The main challenge for LIBS application lies in its low detection sensitivity, especially for liquid sample analysis. When the plasma is induced by a nanosecond laser pulse inside the liquid sample, fast quenching of created plasma occurs, and atomic emission becomes weak in its intensity having a short lifetime. Furthermore, the generation of surface waves during laser ablation reduces reproducibility in liquids. In view of the increasing demand for liquid sample analysis, researchers started exploring the possibility of enhancing the signal-to-background ratio by modifying the sampling approaches and improving the plasma signal by adding new components. For the liquid LIBS technique to reach one of the best ultra-sensitive elemental characterization methods, standardization of the technique and its applicability in real-world problems is highly important. We present our effort to develop different sampling approaches for liquid LIBS signal enhancement. The experimental configurations, optimization of the experimental parameters, and the limit of detection of the proposed sampling approaches are discussed. Finally, we demonstrate their potential application in the agricultural field.

Keywords: Laser Induced Breakdown Spectroscopy (LIBS); Agriculture; Spectroscopy; Liquid Sample;

Topic: GT12: Optical Measurement Methods
Abstract No: 15614

Illumination Variation Robust Circular Target Based on Digital Image Correlation Method

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Content

Circular targets, as one of typical image features, are widely used in image-based measurement, such as photogrammetry, displacement sensing, and vibration monitoring. However, their positioning accuracy are usually sensitive to intensity changes in ambient lighting, particularly in outdoor applications and long-term monitoring scenarios. To address this limitation, a speckle-based circular target (SbCT) is introduced as a solution to improve the localization accuracy in environments with illumination variations. By incorporating a speckle pattern on circular target and utilizing digital image correlation method, the SbCT achieves insensitivity to illumination variations when an appropriate correlation function is selected. This enables accurate and reliable measurements even in challenging lighting cases. The paper outlines the design strategy of the SbCT and describes the extraction procedures. Simulations are conducted to analyze the positioning accuracy of SbCT under linearly varying illumination environment. Furthermore, experiments are performed to validate the robustness of SbCT compared to concentric circular targets, considering both linear and nonlinear lighting variations. The results from both simulations and experiments demonstrate that SbCT is a robust image feature for vision measurement, offering automatic extraction and accurate localization performance even under challenging illumination conditions.

Keywords: Circular targets, Speckle features, Illumination variation, Target localization

Topic: GT12: Optical Measurement Methods
Abstract No: 15629

Extract focus variation data from coherence scanning interferometric measurement

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Content

Coherence scanning interferometry (CSI) can measure surface topography with sub-nanometer precision. Focus variation microscopy (FVM) is a widely used to measure the surface which is optically rough. In this paper, we propose a method to simultaneously obtain CSI fringe data and FVM image stack from a single vertical scanning process using a CSI instrument. Without any hardware modification to the CSI instrument, the surface topography can be determined by fusing the interferometry and FV signals. Since both signals come from the same instrument and scanning process, there is no need for data correlation, registration, or interpolation during the data fusion process. Our method combines the advantages of CSI and FVM measurement, thereby improving the robustness and data coverage of the measurement result.

Keywords: Coherence Scanning interferometry; Focus variation microscopy; Data fusion

Topic: GT12: Optical Measurement Methods
Abstract No: 15630

Compact ARS probe to measure roughness of smooth surfaces

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Content

Measuring the high spatial frequency roughness (spatial frequency > 1 μm^{-1}) of smooth optical surface is important for optics manufacturers. Angle-resolved scattering (ARS) allows for fast, non-contact roughness measurement that is insensitive to environmental disturbances. However, most ARS instruments are based on goniometers, and there is a tradeoff between the roughness measurement bandwidth and the measurement speed. We have developed a compact ARS instrument that covers a spatial frequency range from 1 μm^{-1} to 2.5 μm^{-1}. The instrument allows measurement of an area of 2 mm within 1 minute and the roughness results agree well with atomic force microscopy while providing a pm-level measurement repeatability.

Keywords: High spatial frequency roughness; Angle-resolved scattering; Compact instrument

Topic: GT12: Optical Measurement Methods
Abstract No: 15632

Absolute testing of optical flats using a minimum norm least squares solution

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Content

A laser Fizeau interferometer measures surface form by comparing the wavefront from a reference surface and the surface under test (SUT). The accuracy of large optical flat (aperture > 300 mm) measurements using Fizeau interferometers relies on the reference flat, but the absolute form error of the reference flat is unknown. Absolute testing methods provide a way to obtain this information. In this work, we propose a new absolute testing method using a minimum norm least squares solution. This method uses two calibration flats with accuracy similar to that of the reference flat to implement a three-flat absolute testing. After obtaining three sets of measurements from pairwise comparisons among the three planes, one of the planes is rotated by 90° or 180° to perform the fourth interference measurement. An absolute testing model is established according to the four sets of measurements. This absolute testing equation's minimum norm least squares solution provides the absolute surface for each plane. We verify the method proposed in this paper using a Fizeau interferometer with a 600mm aperture. The experimental results are compared with another absolute testing method based on the odd-even function (requiring over 6 measurements). The absolute form errors of the reference flat obtained by the two methods are in close agreement. However, our proposed method requires fewer measurements, thus enhances the efficiency of absolute testing.

Keywords: Absolute testing; Minimum norm least squares solution; Reference flat; Fizeau interferometer

Topic: GT12: Optical Measurement Methods
Abstract No: 15633

3D measurement of large and complex parts based on phase matching and global marker point registration

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Content

Current requirements resulting from high quality standards and mass production call for an efficient and reliable manufacturing technology. With the aim of meeting the needs of accurate and efficient inspection of massive industrial parts, we propose a novel large-field measurement technique to measure complex reflective surface with large size and weak texture of complex parts. We introduce a small-field-of-view, high-spatial-resolution binocular fringe projection local measurement system, which realizes high-precision point cloud data acquisition of industrial parts' surface based on the principle of heterodyne multi-frequency phase shift and high dynamic measurement. A new point cloud registration method based on phase matching and global marker points is proposed. A global measurement system with large field of view and low spatial resolution system is applied to track the local measurement system and realize the local area point cloud registration of large industrial components. The global marker points on the surface of the turntable jointly calibrated by the laser tracker and the vision system is presented to realize the registration of all areas of the component. A global optimization with trimmed ICP is applied for adaptive fine registration of multi-view point clouds with different overlap rates to eliminate accumulated errors. The proposed system can achieve a global measurement range of 4m×4m×2.5m, and the experimental results demonstrate the effectiveness of the proposed method for high-precision measurement of industrial complex parts with large field of view, which effectively avoid the transmission error and benefits the inspection and manufacturing of industrial parts.

Keywords: Multiview 3D measurement; Phase matching; Global marked point registration; Point cloud

Topic: GT12: Optical Measurement Methods
Abstract No: 15634

Quality Inspection and Assembly Sequence Optimization of Revolved Thin-walled Parts Based on Point Clouds

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Content

To address the challenges in evaluating assembly quality for revolved thin-walled parts, a novel algorithm was developed that combines virtual assembly and quality assessment. Leveraging 3D point cloud data, the algorithm employs various techniques for accurate assembly assessment. Initial registration using an Oriented Bounding Box (OBB) achieved rough alignment, followed by precise registration using point-to-plane Iterative Closest Point (ICP) to minimize RMS error to 0.173mm. Contour points on cross sections were extracted through resampling. Transverse section contours were effectively fitted using least square circle fitting. However, due to its randomness, least square ellipse fitting for longitudinal section contours struggled to meet precision standards. To quantify part manufacturing errors, RMS radial distances from longitudinal section contour points to theoretical ellipses were utilized. The algorithm then calculated the assembly sequence with the least error. Detection of assembly interference was realized by measuring distances between transverse section contour boundary points. Simulated point cloud data validated the algorithm's efficacy in effectively assessing part quality, optimizing assembly sequences, and identifying assembly interference. By combining innovative registration, contour analysis, and error quantification techniques, the algorithm offers a promising solution for ensuring assembly quality and reliability, addressing the challenges posed by irregular revolved thin-walled parts.

Keywords: Point cloud registration; Contour extraction; Optimization of assembly sequence; Revolved thin-walled parts

Topic: GT13: Quantitative Phase Imaging
Abstract No: 15460

Non-interferometric optical diffraction tomography with Fourier ptychography

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Content

Optical diffraction tomography (ODT) is a promising label-free three-dimensional (3D) microscopic method capable of measuring the 3D refractive index (RI) distribution of optically transparent samples, which has shown practical value in biological research and drug discovery. In recent years, the non-interferometric ODT techniques represented by Fourier ptychographic diffraction tomography (FPDT), have received increasing attention for their system simplicity, speckle-free imaging quality, and compatibility with existing microscopes. However, to ensure sufficient overlap of Ewald spheres in 3D Fourier space, conventional FPDT requires thousands of intensity measurements and consumes a significant amount of time for stable convergence of the iterative algorithm. To address this issue, we present accelerated Fourier ptychographic diffraction tomography (aFPDT), which employs a hybrid strategy of sparse annular LED illuminations and multiplexing illumination to significantly decrease data amount by 40 times and achieves large field-of-view and high-resolution RI tomographic imaging. In addition, ODT methods for implementing non-interferometric measurements in high numerical aperture (NA) microscopy systems are often plagued by low-frequency missing problems — a consequence of violating the matched illumination condition. Here, we present transport-of-intensity Fourier ptychographic diffraction tomography (TI-FPDT) to address this challenging issue by combining ptychographic angular diversity with additional transport-of-intensity measurements. Exploiting the defocused phase contrast to circumvent the stringent requirement on the illumination NA imposed by the matched illumination condition, TI-FPDT effectively overcomes the reconstruction quality deterioration and RI underestimation problems in conventional FPDT and is anticipated to open new possibilities for label-free 3D microscopy in various biomedical applications.

Keywords: Optical diffraction tomography;Fourier ptychographic diffraction tomography;Refractive index imaging;3D microscopy

Topic: GT13: Quantitative Phase Imaging
Abstract No: 15461

Transport of intensity diffraction tomography with non-interferometric synthetic aperture for three-dimensional label-free microscopy

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Content

We present a new label-free three-dimensional (3D) microscopy technique, termed transport of intensity diffraction tomography with non-interferometric synthetic aperture (TIDT-NSA). Without resorting to interferometric detection, TIDT-NSA retrieves the 3D refractive index (RI) distribution of biological specimens from 3D intensity-only measurements at various illumination angles, allowing incoherent-diffraction-limited quantitative 3D phase-contrast imaging. The unique combination of z-scanning the sample with illumination angle diversity in TIDT-NSA provides strong defocus phase contrast and better optical sectioning capabilities suitable for high-resolution tomography of complex multi-layer biological samples. Based on an off-the-shelf bright-field microscope with a programmable lightemitting-diode (LED) illumination source, we demonstrate the achievable imaging resolution of TIDT-NSA at 206 nm laterally and 0.52 um axially with a high-NA oil immersion objective and validate the 3D RI tomographic imaging performance on various unlabelled fixed and live samples, including human breast cancer cell lines MCF-7, human hepatocyte carcinoma cell lines HepG2, mouse macrophage cell lines RAW 264.7, multicellular Caenorhabditis elegans (C. elegans), and live Henrietta Lacks (HeLa) cells. These results establish TIDT-NSA as a new non-interferometric approach to optical diffraction tomography and 3D label-free microscopy, permitting quantitative characterization of cell morphology and time-dependent subcellular changes for widespread biological and medical applications.

Keywords: Computational Microscopy, 3D imaging, Diffraction tomography, Phase retrieval

Topic: GT13: Quantitative Phase Imaging
Abstract No: 15578

Aberration-free high bandwidth holographic imaging

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Content

Objective measurements of the morphology and dynamics of label-free cells and tissues can be achieved by quantitative phase with low phototoxicity and no photobleaching. The morphology and dynamics of label-free tissues can be exploited by sample-induced changes in the optical field from quantitative phase imaging. Its sensitivity to subtle changes in the optical field makes the reconstructed phase susceptible to phase aberrations. We import variable sparse splitting framework on quantitative phase aberration extraction in holographic microscopy. By formulating the aberration extraction as a convex quadratic problem, the background phase aberration can be fast and directly decomposed with the specific complete basis functions such as Zernike or standard polynomials. We integrate the proposed framework into the high bandwidth holographic microscopy. The aberration-free two-dimensional and three-dimensional imaging experiments are demonstrated, showing the relaxation of the strict alignment requirements for the holographic microscopes.

Keywords: Digital holography, Phase retrieval; Aberration

Topic: GT13: Quantitative Phase Imaging
Abstract No: 15610

3D Quantitative Phase Imaging for studying Human Red Blood Cells

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Content

RBCs are essential for carrying oxygen throughout the body. Maintaining human health requires an understanding of the various RBC types, their structural defects, and the difficulties in identifying these abnormalities. RBCs are commonly divided into sickle cells, discoid cells and other abnormalities . Hemoglobinopathies including sickle cell disease, thalassemia, and genetic spherocytosis, as well as acquired syndromes like anaemia, which can be brought on by dietary shortages or long-term illnesses, are few examples of the wide range of RBC abnormalities. Advanced imaging techniques are necessary for identifying and characterizing these anomalies. Label-free, non-invasive, and high-resolution imaging of RBCs is made possible by QPI techniques like the Transport of Intensity Equation (TIE). With the use of TIE-based 3D QPI, we have extracted quantitative features like cell volume, cell height and cell surface area of human RBCs from the captured images. This method enables characterization that is more accurate and diagnosis of diseases by providing insights into the structural modifications linked to RBC abnormalities.

Keywords: Quantitative Phase Imaging, Red Blood Cells, label-free

Topic: GT13: Quantitative Phase Imaging
Abstract No: 15622

Differential phase contrast quantitative phase imaging based on optimal modulation of asymmetric illumination

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Content

With the emergence of the new concept of "computational optics", label-free microscopic imaging based on optical modulation mechanisms has been flourishing. This has led microscopic imaging technology from “two-dimensional” to “three-dimensional”, from “qualitative observation” to “quantitative detection”. Differential phase contrast (DPC) is a typical representative. It is based on the phase modulation effect of asymmetric illumination to achieve the inverse solution of the recorded intensity to the quantitative phase of the sample. Based on the transfer function optimization theory, we investigate the quantitative influence of coherence modulation on the transfer function and analyzes the coherence modulation schemes under the optimization of imaging performance and imaging efficiency. This not only empowers quantitative phase imaging with high resolution, high contrast, high stability and real-time dynamic imaging, providing nano-scale 3D morphological information and millisecond-level time-domain resolution.

Keywords: Differential phase contrast; quantitative phase imaging; optimal; phase transfer function; asymmetric illumination

Topic: GT13: Quantitative Phase Imaging
Abstract No: 15626

High-throughput artifact-free slightly off-axis holographic imaging based on Fourier ptychographic reconstruction

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Content

In the field of optical microscopy, quantitative phase imaging (QPI) is an essential tool for biomedical research, possessing the distinctive ability of optical thickness measurement of live cells without exogenous contrast agents. As a classical QPI technique, digital holographic microscopy (DHM) combines interferometric technique, modern CCD sensor and image processing systems, allowing for single-shot digital real-time recording and numerical reconstruction of the object wavefront to quantitatively recover amplitude and phase. Since the spectral aliasing degree of object information and background intensity affects the phase demodulation accuracy directly through the linear Fourier domain filtering, conventional holography suffers from the problem of incompatibility between high reconstruction quality and high throughput imaging. The enhancement of space-bandwidth product by slightly off-axis holography is necessarily accompanied by zero-order suppression; otherwise, artifacts will be formed on the phase image due to the residual background intensity information. We innovatively propose a zero-order suppression method for slightly off-axis digital holography based on Fourier ptychography, terms as FPDH. Inspired by the FPM phase retrieval process, the hologram spectrum recovery is viewed as a nonlinear optimization problem, and the object wavefront is recovered by a method like GS algorithm. In the premise that the linear method cannot correctly solve for the object wavefront, FPDH is more universal with no constraint on the intensity of two coherent beams and unconstrained spectral configuration, which is distinct from all previous off-axis holography phase recovery methods. Experimental results show that FPDH can provide higher reconstruction accuracy and better image quality compared with other methods.

Keywords: digital holographic microscopy, quantitative phase imaging, space-bandwidth product, Fourier ptychography, nonlinear optimization

Topic: GT13: Quantitative Phase Imaging
Abstract No: 15663

High-speed 3D imaging and metrology: from classical fringe projection to deep learning approaches

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Content

Fringe projection profilometry (FPP) is one of the most representative 3D imaging technologies due to its non-contact, high-resolution, and full-field measurement capability. In recent years, “high speed” has gradually become a fundamental factor that must be taken into account when using FPP, and high-precision 3D reconstruction using only one single pattern has been the ultimate goal of structured light 3D imaging in perpetual pursuit. Nowadays, deep learning technology has fully “permeated” into almost all tasks of optical metrology. In this talk, we introduce our recent efforts to apply deep-learning approaches to FPP. We show that the deep-learning-enabled fringe analysis approach can significantly boost the accuracy and improve the quality of the phase reconstruction compared to conventional single-fringe phase retrieval approaches. Deep learning can also be used to achieve single-frame, high-precision, unambiguous 3D shape reconstruction, which is expected to fill the speed “gap” between 3D imaging and 2D sensing and enables FPP techniques to go a step further in high-speed and high-accuracy 3D surface imaging of transient events.

Topic: GT15: Ultrafast Lasers and Applications
Abstract No: 15637

A simulation on quasi-phase-matched high-harmonic generation in gas-filled hollow core waveguide

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Content

Coherent EUV or soft X-ray sources have many applications in industry and fundamental research. Although these sources are available in the large facility centres such as synchrotron or free electron laser, high-harmonic generation (HHG) can provide us a table-top approach. However, coherent EUV or soft X-ray sources based on HHG normally suffer a very low photon flux. Quasi-phase-matching (QPM) techniques can be applied to enhance the HHG photon flux. Here, we apply multimode quasi-phase-matching of HHG in gas-filled hollow core waveguide in the simulation. The quasi-phase-matching is achieved by inducing mode beating between pairs of waveguide modes. A pair of pulses with adjustable relative delay is coupled into the waveguide. The mode beating happens exactly at the end of the hollow core waveguide by controlling the intermodal delay. The simulation shows that the photon flux of HHG is much enhanced by intermodal delay controlled QPM. The detailed simulation results will be presented. These results are very important for developing the HHG based coherent EUV or soft X-ray sources with higher photon flux.

Keywords: EUV; High harmonic generation; Quasi-phase-matching; Hollow core waveguide

Topic: GT15: Ultrafast Lasers and Applications
Abstract No: 15507

Uniform LIPSS on Copper Created Using Zeroth-Order Femtosecond Bessel Beam for SERS-based Applications

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Content

The present study is about the generation of Laser-induced periodic surface structure (LIPSS) with the interaction of femtosecond (50 fs) amplifier pulses (1 kHz, 800 nm) in the form of a non-diffracting, propagation invariant, zeroth-order Bessel beam. We performed laser ablation in the air (LAA) with the focused, axicon-generated fs Bessel beam. We aimed to investigate the novel, highly uniform, large-area, ladder-step-like nanostructures through laser-matter interaction. The target material used was copper (Cu), and the experimental process involved imprinting the beam profile on a single spot of the Cu surface, followed by overlapping two ablation zones. Nanoscale topographical developments were extensively characterized using field emission scanning electron microscopy (FESEM) and atomic force microscopy (AFM). The investigation focused on the central lobe ablated region and concentric rings-ablated exciting patterns. Remarkably, the raster scan ablation created ladder-like periodic surface structures with sub ~15 nm spherical, aspherical nanogrowths. Energy dispersive X-ray (EDX) mapping also confirmed elemental distribution and surface oxidation in the engineered areas. Afterwards, the laser-engineered plasmonic surface was engaged as a surface-enhanced Raman scattering (SERS) substrate to detect traces of secondary explosives such as Tetryl (TL) and PETN in real-time. The obtained SERS spectra of TL and PETN unveiled signature Raman mode peaks at 1357 cm^{-1} and 1292 (cm^{-1}), with the lowest possible detected traces at 5 μM and 1 mM concentrations.

Keywords: Copper nanostructures; LIPSS; Femtosecond; Bessel beam ablation; SERS

Topic: GT15: Ultrafast Lasers and Applications
Abstract No: 15649

Versatile GHz burst-mode operation in high-power femtosecond laser for industrial applications

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Content

Femtosecond lasers have emerged as an important tool for achieving high-precision micromachining across various materials, offering minimal thermal effects and unprecedented accuracy. Increasing interest from industry in femtosecond laser technology, initiated advancements in the ultra-fast laser field. New features are being developed and here we present a novel method for generating gigahertz (GHz) repetition rate bursts of ultrashort laser pulses within an all-fiber system [1]. This innovative approach utilizes an active fiber loop (AFL), enabling the formation of bursts with customizable intra-burst repetition rates (PRR), independent of the initial PRR of the fiber oscillator. This technique demonstrated the creation of bursts containing 2 to 1100 pulses, each with identical intra-burst PRR of >2 GHz. Furthermore, this breakthrough technology has been succesfully integrated into the industrial FemtoLux 30 femtosecond laser system, expanding its operational capabilities to short, long GHz burst regimes [2] and burst-in-burst regime. The successful integration of GHz burst formation technology not only enhances the performance of femtosecond laser systems but also opens up new avenues in the field of material micromachining [3].

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Topic: GT16: Other Related Topics
Abstract No: 15495

Tuning the third-order nonlinear optical properties of methyl orange via adding plasmonic nanoparticles and protonation

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Content

In order to realize optical limiting (OL), it is necessary to utilize materials that exhibit distinct traits, such as a large and rapid nonlinear optical response, good nonlinear absorption (NLA), high photothermal stability, and cost-effectiveness. In this work, we investigated two effective strategies for modifying the nonlinear optical properties (NLO) of methyl orange (MO), a popular pH indicator, a potential nonlinear material, and an azo dye of great industrial importance. The first is forming a nanohybrid system with Au and Ag metal nanoparticles. In the second method, the nonlinear optical response is modified by inducing conformational and structural changes in MO through protonation. A considerable enhancement is observed in the NLA and OL performance MO-Ag and MO-Au nanohybrid compared to its constituent compounds, and it is attributable to photoinduced charge transfer between MO and metal NPs as well as the local field effect of NPs. Compared to MO, the nonlinear absorption coefficient of protonated-MO increased significantly, and it can be attributed to the redistribution of energy levels of MO, which favored resonant absorption in the system. The mechanism behind the NLA and OL activity is found to be the combined effects of two-photon absorption and excited state absorption. The closed aperture Z-scan measurements shows that all the samples exhibited negative nonlinear refraction. These findings indicate that these strategies are an efficient way to modify the NLO response of MO and are directly applicable promise for a wide range of nonlinear optical applications, including but not limited to optical limiting.

Keywords: methyl orange, Nonlinear optics, optical limiting, z-scan, protonation

Topic: GT16: Other Related Topics
Abstract No: 15508

Point cloud pair constraint registration algorithm based on directed distance function

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Content

Because blade machining is limited by machining technology and machining allowance tolerance, the distribution of machining allowance needs to be optimized under multiple constraints. Aiming at the constraints of machining freedom and machining allowance distribution, a bidirectional point cloud registration method under multiple constraints is proposed. A minimum region point cloud registration method based on point-to-curve distance function is established. The processing constraints are assigned to the source point cloud before registration, and the processing margin distribution constraints are iteratively processed during the point cloud registration process, and the processing constraints are adjusted according to the feedback of the iteration results. The test results show that the optimization method proposed in this paper can better meet the requirement of machining allowance distribution under multiple constraints, and increase the machinable rate of the workpiece.

Keywords: Machining allowance optimization; Point cloud registration; Minimum region method; Blade profile

Topic: GT16: Other Related Topics
Abstract No: 15542

Tunable All-Optical Diode Action in Polymeric Photonic Crystals with Photonic Band Edge Effects

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Content

We report the experimental realization of an all-optical diode based on two axially asymmetric nonlinear optical media. The diode is fabricated by juxtaposing a saturable absorber (SA) and a reverse saturable absorber (RSA) in tandem. The asymmetry in nonlinear absorption leads to non-reciprocity in light transmission, which makes the output transmittance from the nonlinear medium direction dependent. The optical diode consists of a layer of PEDOT:PSS as a saturable absorber medium and a 1-D polymer photonic crystal containing a gold-carbon (Au@C) core-shell structure at alternating layers as a reverse saturable absorber medium. The long-wavelength photonic band-edge of the polymeric photonic crystal was designed at 532 nm to enhance the non-resonant nonlinear absorption of the core–shell nanostructure. Forward and reverse direction action of the diode was demonstrated by varying the input fluence of a Q-switched Nd: YAG laser operating at 532 nm.

Keywords: optical diode, PEDOT:PSS, reverse saturable absorption, photonic crystal

Topic: GT16: Other Related Topics
Abstract No: 15609

In-house Developed Ultra-Sensitive Laser Stimulated Fluorescence System for Metabolic Profiling

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Content

Advancements in biophotonics have significantly enriched various scientific and technological fields. Among these, fluorescence spectroscopy stands out as a widely embraced technique by chemists, pharmacologists, biologists, and medical professionals. The versatility of fluorescence spectroscopy has spurred its adoption in diverse medical science domains for both research and diagnostic purposes. This study introduces an innovative approach to simultaneously detect amino acids through high performance liquid chromatography combined with laser-stimulated fluorescence detection, displaying an impressive femtomolar detection limit. The qualitative and quantitative assessment of amino acids holds immense significance in the realm of life sciences. It assumes a pivotal role in comprehending intricate biological processes and, importantly, in the early detection of potential disease developments as amino acids serve as precursors for numerous biomarkers. In this context, our metabolic profiling method offers remarkable versatility, positioning it to scrutinize amino acid profiles in body fluids. This capability opens doors to an array of diagnostic applications, including the identification of transport disorders, evaluation of renal function, diagnosis of neuropathy disorders, and the detection of inborn errors of metabolism like phenylketonuria and maple syrup urine disease. By harnessing the power of laser-stimulated fluorescence detection, our approach offers a novel pathway to enhance the understanding of amino acid's roles in health and disease. The remarkable sensitivity of femtomolar detection empowers the identification of subtle changes in amino acid concentrations that might signal the onset of various medical conditions. Ultimately, this innovative technique presents a promising tool for advancing medical diagnostics and enabling proactive interventions.

Keywords: Fluorescence spectroscopy, laser stimulated fluorescence, amino acids and femtomoles.

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Topic: SS1: 2D, 3D and volumetric digital image correlation and their applications
Abstract No: 15489

The theory and error analysis of crack propagation measurement for brittle materials based on virtual principal strain field

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Content

To study the fracture mechanical properties of brittle materials, this paper proposes an accurate and non-destructive method for measuring geometric parameters of crack propagation based on virtual principal strain field which can be obtained by digital image correlation (DIC) technique. The mechanism of crack-induced virtual principal strain field and the effects of subset size, step size and strain window size are analyzed and discussed theoretically for the first time. The effectiveness of the derived theoretical equations is verified by the simulation experiments. It is found that that the distribution of virtual principal strain field near the crack is similar to the grayscale distribution of imaged laser fringe, and the crack centreline can be extracted from the virtual principal strain field by using the Steger algorithm. The difference between displacement vectors on two sides of the crack centreline is obtained and the projection on the normal direction and tangent direction are taken as the opening and sliding of cracks respectively. The experiment of simulating crack propagation is performed by using a high precision translation table to verify the measurement accuracy. The experimental results show that the minimum crack identified by the proposed method is at least 0.362 pixel and related to the strain noise, while the measurement error of crack width is less than 0.02 pixel. The propagation of mode I cracks in the bending experiment of seawater sea sand BFRP concrete beam were monitored in real-time using the proposed method.

Keywords: Crack propagation, Brittle materials, DIC, Virtual principal strain, Steger algorithm

Topic: SS1: 2D, 3D and volumetric digital image correlation and their applications
Abstract No: 15576

Transformer-based deep learning for digital image correlation

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Content

Complex deformation containing highly localized displacement fields remains a challenge to digital image correlation (DIC) measurement. The window-processing nature makes traditional DIC incapable of handling this kind of case, as the window (also called subset) needs to be large enough to guarantee unique speckle pattern within it for successful subset matching between the reference image (before deformation) and the target image (after deformation). Furthermore, specific shape function is employed to describe the deformation in subset, which also leads to the dilemma of under-estimation and over-estimation of deformation. To solve this intractable issue, deep learning model is introduced recently into DIC, which endows the image matching with variable view field of perception. Relevant study reported heretofore is based on convolutional neural network (CNN), which is a major model widely used in computer vision. In this paper, we developed a new DIC method based on Transformer, which is a major model for natural language processing but show its peculiar advantages in image processing. Experimental study demonstrates that the transformer-based DIC method reaches higher measurement accuracy while keeps equivalent robustness to complex deformation, in comparison with the CNN-based DIC methods. This superiority is ascribed to the perception mechanisms of transformer, which enhance the ability to extract latent features in speckle images.

Keywords: Digital image correlation; Deformation measurement; Deep Learning; Transformer; Optical flow

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15616

Phase-shift Error Estimation Based on Deep Learning

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Content

Phase-shift interferometry is a high-precision and commonly used phase retrieval method. In practical applications, phase-shift errors are usually introduced due to factors such as environmental disturbances and phase shifter error. In this paper, we propose a deep learning method for estimating phase-shift error from phase-shifted interferograms. This method manages to process the four interferograms with phase shift π/2, and uses neural network to extract phase-shift errors from four interferograms. The analysis shows that the proposed method can effectively estimate the phase-shift error under the noisy interferograms. This method can be used to correct phase-shift errors for phase retrieval (e.g., the least squares phase retrieval method) and calibrate phase shifters.

Keywords: phase-shift error; deep learning; neural network; phase retrieval;

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15525

Measurement depth maximization of geometric constraint based on phase-to-space error analysis

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Content

As an important phase unwrapping method in fringe projection, the geometric constraint enables pixel-by-pixel computation while avoiding the projection of additional patterns. However, its measurement depth is limited to one fringe period and is determined by practical spatial configuration of the projector-camera system. In this paper, to extend the measurement depth to the theoretical maximum, we derive a generalized phase-to-space error model and analyze the technical bounds of geometric constraint. Based on this analysis, we propose a method to maximum the measurement depth by adjusting the projector-camera system to a near-parallel state. Comprehensive simulations and experiments are conduct, and the results successfully demonstrate the effectiveness of the theory and the proposed method.

Keywords: Fringe projection, Phase unwrapping, Geometric constraint, Measurement depth maximization, Spatial error model

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15554

Body scanning and anthropometric data extraction based on a multi-view structred light 3D imaging system

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Content

Body measurement has great value in the fields of fashion industry, health care, sports science, entertainment and so on. In this paper, a multi-view structured light three dimensional (3D) imaging system is descried, which can perform rapid 3D reconstruction of the human body and automatically extract anthropometric data from it. This system contains 12 sets of 3D imaging sensors distributed on four pillars. Each 3D imaging sensor consists of a binocular stereo system, an Infrared laser projector and a synchronous control system based on the Field Programmable Gate Array (FPGA). The projector provides phase-shifting fringe patterns and gray code for the binocular stereo system to make 3D reconstruction. The FPGA control system enables the sensor to achieve high speed scanning. A two-step calibration method is used to calibrate the internal and external parameters of each 3D imaging sensor and external parameters between these sensors. After the 3D human body data acquisition, major body joints will be extracted as key-points. In this process, the initial location of these key-points are extracted based on a deep learning method, and then they are further corrected with local point cloud analysis. With the assist of these key-points, the anthropometric data, such as distances (lengths, breadths, heights) and circumferences of human body, can be calculated from its 3D data. Based on the techniques described above, the multi-view 3D imaging system can complete the whole body scanning in 2 seconds and automatically measure more than sixty dimensional data after analyzing the reconstructed 3D human data.

Keywords: three dimensional imaging, multi-view, body measurement, anthropometric data, deep learning

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15568

Prototype of High-brightness Fringe Projector Using Line LED Device and Cylindrical Lens Array

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Content

A 3D measurement method based on a fringe projection method using a whole-space tabulation method (WSTM) and a feature quantity type WSTM (F-WSTM) were proposed recently in our laboratory. It is possible to measure 3D coordinates at high speed by using a relation table between the phase and the coordinates using a light-source-stepping method (LSSM). High-speed phase shift can be achieved by switching the lighting position of the linear LED using the LSSM.

The half power of emitted light is, however, unutilized because a Ronchi ruling is used for producing projected fringe patterns in the conventional LSSM. Therefore, we proposed a method to project fringe patterns using a cylindrical lens array instead of a Ronchi ruling as a fringe generating device. It is expected that the two times brightness fringe pattern can be projected with this device.

In this study, we fabricate and evaluate a fringe projection device using a manufactured cylindrical lens array with specifications suitable for fringe projection. As the result, it was confirmed that brightness and amplitude of the projected fringe are very high and effective.

Keywords: 3D shape measurement, Line LED device, Cylindrical Lens Array

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15579

Three-dimensional shape measurement of diffused/specular surface by combining fringe projection profilometry and phase measuring deflectometry

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Content

Three-dimensional (3D) data of object surfaces play an important role in the fields of aerospace, automotive industry, augmented reality, heritage preservation, smart city, etc. The existing fringe projection profilometry and deflectometry can only measure the 3D shape of diffused and specular surfaces, respectively. However, there are many components having diffused/specular surfaces. It is a challenging problem to simultaneously measure their 3D shape accurately. This talk will present a novel method for measuring the 3D shape of diffused/specular surfaces by combing fringe projection profilometry and phase measuring deflectometry. A mathematical model has been derived to directly build up the relationship between the depth and absolute phase data. After calibrating the system parameters, the shape information of the tested objects can be constructed in the same coordinate system from the captured deformed fringes. The digital light processing (DLP) projector and liquid crystal display (LCD) screen simultaneously project and display fringe patterns through red, green and blue channels. The deformed fringe patterns are captured by a color camera from a different viewpoint to improve measurement efficiency. Experimental studies are conducted with an artificial step having diffused/specular surfaces to verify the measurement accuracy. The results on several objects show that the proposed method can measure diffused/specular surfaces effectively with certain accuracy. Error sources are also analyzed to improve the measurement accuracy.

Keywords: Composite reflection surface; Fringe projection and reflection; System calibration; Multi-color channel

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15590

Indoor simultaneous localization and mapping based on fringe projection profilometry

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Content

Simultaneous Localization and Mapping (SLAM) plays an important role in outdoor and indoor applications ranging from autonomous driving to indoor robotics. Outdoor SLAM has been widely used with the assistance of LiDAR or GPS. For indoor applications, the LiDAR technique does not satisfy the accuracy requirement and the GPS signals will be lost. An accurate and efficient scene sensing technique is required for indoor SLAM. As the most promising 3D perceiving technique, the opportunities for indoor SLAM with fringe projection profilometry (FPP) systems are obvious, but methods to date have not fully leveraged the accuracy and speed of sensing that such systems offer. In this paper, we propose a novel FPP-based indoor SLAM method based on the coordinate transformation relationship of FPP, where the 2D-to-3D descriptor-assisted is used for mapping and localization. The correspondences generated by matching descriptors are used for fast and accurate mapping, and the transform estimation between the 2D and 3D descriptors is used to localize the sensor. The provided experimental results demonstrate that the proposed indoor SLAM can achieve the localization and mapping accuracy around one millimeter.

Keywords: Fringe projection profilometry; Simultaneous Localization and Mapping; Indoor 3D perceiving

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15592

Adaptive-resolution-based high-resolution indoor 3D perceiving in fringe projection profilometry

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Content

Fringe projection profilometry (FPP) is one of the most widely used optical three-dimensional (3D) perceiving techniques. However, for indoor 3D perceiving, acquiring high-resolution 3D data is difficult because of the trade-off between sampling resolution and measurement scale. In this paper, an adaptive resolution FPP method is proposed to achieve high-resolution indoor 3D perceiving. Specifically, the super-resolution reconstruction methods is introduced to improve the resolution of the captured fringe patterns. Due to the powerful data mining capability of deep learning, an end-to-end fringe pattern super-resolution network (FPSRNet) is constructed, which can be trained to transform the captured low-resolution fringe patterns into the desired high-resolution fringe patterns. The provided experiments verify that the proposed method can achieve high-resolution 3D perceiving without sacrificing accuracy.

Keywords: Fringe projection profilometry; Indoor 3D perceiving; Super-resolution

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15604

Multi-dimensional information sensing based on DIC-assisted fringe projection profilometry

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Content

Multi-dimensional and high-resolution information sensing of complex surface is critical for the investigation of various structures and understanding their mechanical properties. Fringe projection profilometry (FPP) has been widely applied in shape measurement of complex surfaces. Since structured light information is projected instead of being attached onto the surface, it becomes challenging to accurately track corresponding point and fails to further analyze the deformation and strain. To address this issue, we propose a multi-dimensional imaging method based on digital image correction (DIC)-assisted FPP. Colorful fluorescent markers are firstly introduced to produce modulated information with both high intensity reflectivity and color difference. And then, the general information separation method is presented to simultaneously acquire speckle-free texture, fringe patterns and high-contrast speckle patterns for multi-dimensional information sensing using the developed DIC-assisted FPP method. The proposed method simultaneously realizes accurate and high-resolution 2D texture, 3D shape and 4D deformation and strain sensing on complex structures. Experimental results demonstrate the proposed method can bridge 2D texture, 3D geometry and mechanical state of complex specimens and expand the measuring dimension of the off-the-shelf FPP system without any hardware cost.

Keywords: Digital image correlation; fringe projection profilometry; shape measurement; strain measurement

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15619

Theoretical Analysis and Discussion of The Measurement Methods in Fringe Projection Profilometry

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Content

Fringe projector profilometry (FPP) is a significant non-interferometric optical measurement technique due to its high-precision, high-speed and low-cost. In our previous work, we clarified the relationship between epipolar line and optimal angle fringes being parallel. We then proposed a novel FPP measurement method called OptE3, which projects only one set of optimal angle fringes and together with the epipolar line for precise metching between the camera and the projector pixels. Although OptE3 has advantages of efficiency, high precision, and convenience, traditional method (projecting one set of horizontal or vertical fringes) tend to be favored due to its simplicity. To facilitate readers in making a more reasonable choice between OptE3 and traditional method, this paper tries to answer two questions: (1) how much do the measurement precisions of the two methods differ, and (2) under what conditions are the measurement precisions of the two methods equal? To answer this question, we derive measurement precision models for the two methods separately. Furthermore, we link the precision models of both methods using optimal angle. Finally, we provide the system configuration conditions for two methods yield equal results.

Keywords: Fringe projector profilometry; Epipolar Line equation; Non-Interferometric Optical Measurement

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15655

The way towards AI-based high-speed structured light 3D imaging

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Content

Optical metrology is playing a significant role in many fields because of its merits of noninvasiveness, flexibility, and high accuracy. In optical metrology, fringe-pattern analysis is indispensable to many tasks, e.g., interferometry, fringe projection profilometry, and digital holography. In recent years, many advances have emerged in the field of optical metrology that benefit from harnessing the power of deep learning. The fringe-pattern analysis using deep learning has shown promising performance in measuring complex contours by using a single fringe image. As a data-driven approach, it can exploit useful hidden clues that may be overlooked by traditional physical models, thus showing potentials for resolving the contradiction between the efficiency and the accuracy in the phase demodulation. In this talk, I will review the basics, achievements and newest developments of deep-learning-based approaches for high-speed real-time structured light 3D imaging, such as fringe pattern analysis, phase unwrapping, and 3D reconstruction.

Keywords: Optical metrology; fringe projection profilometry; fringe pattern analysis; 3D reconstruction; deep learning

Topic: SS2: 3D shape measurement based on fringe projection
Abstract No: 15671

3D Reconstruction of Dynamic Object Based on Improved Deep Optical Flow Tracking

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Content

Dynamic object reconstruction based on phase-shifting profilometry has been attracted intensive research in recent years. The measurement error caused by object motion can be addressed successfully by tracking the object movement. However, it either requires a high-cost color imaging equipment or is limited by the assumption of 2D translation movement. A new method to reconstruct the dynamic object with any 2D movement sensed by affordable monochrome camera is presented. An improved RAFT optical flow algorithm is proposed to track the object based on the object fringe pattern image directly. The feature points on the object are retrieved immune to the fringe pattern illumination. Then, the RANSAC algorithm and an iteration selection process are employed to select feature points with high quality optical flow. At last, the motion is described mathematically and the dynamic object is reconstructed successfully.

Topic: SS3: Advances in Digital Holography Techniques
Abstract No: 15605

Real-time 3D scenes acquisition method for light field 3D display

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Content

3D displays are undergoing rapid development in recent years. With the trend of high-performance 3D displays, the real-time 3D scenes acquisition is a research hotspot. In this paper, a real-time 3D scenes acquisition method for light field 3D displays based on the calculated depth map is proposed and a real-time 3D scenes acquisition system is also presented. We utilize a color camera to capture the 2D video stream as the only input to reduce the system's complexity. Simultaneously, a neural network is presented to predict the corresponding depth maps of the 2D video frames. With the usage of corresponding depth maps, the multiple perspectives of each 2D video frame are obtained. To avoid the rendering redundant information in parallax images with dense viewpoints, a method for calculating multiple 2D pixels value corresponding to the same 3D point is proposed. Descriptive and mathematical definitions of the parallax relationship in 3D scenes acquisition are formalized and summarized. Also, a CPU&GPU heterogeneous parallel computing acceleration method is proposed to synthesize the virtual views, fill the holes and generate the final 3D content for a light field 3D display. The presented system consists of 4 segments: a color camera, a network, a computer and a light field 3D display with 28 viewpoints. The real-time performance of the proposed method is verified in the presented 3D scenes acquisition method.

Keywords: 3D scenes acquisition, real time, depth map.

Topic: SS3: Advances in digital holography techniques
Abstract No: 15498

Engineering Axial Resolution Realtime and Post-Recording of Incoherent Holograms Using Hybridization Techniques

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Content

In incoherent digital holography (IDH) and in any imaging technique, the lateral and axial resolutions are intertwined and consequently changing one characteristic affects the other. In this study, we present two new hybridization techniques for IDH, one for real-time and another for post-recording of holograms, to engineer the axial resolution independent of lateral resolution. Two optical functions namely a lens and an axicon are considered. In both hybridization techniques, the axial resolution can be tuned between the limits of the axial resolutions of lens and axicon, while maintaining a constant lateral resolution. In the first hybridization method, the axial resolution was engineered using a special phase mask designed using a modified version of Gerchberg-Saxton algorithm that can generate a spherical beam and Bessel beam and create self-interference for every object point. By controlling the strengths of the two beams, the axial resolution can be tuned without changing the lateral resolution. This method requires an active optical device such as a spatial light modulator. The second approach involves two recordings of the same scene, one with a lens and another with an axicon which are then combined. By controlling the weights of the two recordings, the axial resolution can be tuned between the limits of lens and the axicon independent of lateral resolution. In this case, passive optical elements are sufficient. Both hybridization techniques are implemented in indirect imaging mode consisting of three steps: recording point spread hologram and object hologram and reconstruction by Lucy-Richardson-Rosen algorithm.

Keywords: Digital holography; Incoherent Imaging; Lucy Richardson Rosen Algorithm; Coded Aperture Imaging; Computational Imaging

Topic: SS3: Advances in digital holography techniques
Abstract No: 15529

Surface Plasmon Resonance Holographic Microscopic Imaging Technology and Application Research

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Content

Surface plasmon resonance holographic microscopy (SPRHM) is a near-field quantitative microscopy imaging technique that combines surface plasmon microscopy (SPM) with digital holographic microscopy (DHM). The near-field optical signal carrying the sample information can be recorded in the far-field by digital holography. Therefore, changes in the physical parameters of the dielectric samples in the near-field region can be quantitatively demodulated with high-sensitivity, label-free in a wide-field at the micro-nano scale. Benefiting from the advantages of SPRHM capable of realizing complex amplitude imaging, it has potential applications in the fields of life science, atomic layer materials and electrochemistry. In recent years, the main research direction of SPRHM has focused on the exploration of its application prospects, while ignoring its problems in the imaging process—the imaging quality is lower than that of traditional optical microscopes and traditional DHM. The poor spatial resolution of SPRHM limits its further development. To this end, we have carried out theoretical research and experimental exploration on the imaging mechanism of SPRHM and the generation of image tails. Furthermore, several methods for improving the resolution of SPRHM imaging were proposed and applied to research fields such as the imaging of cell-attached gaps, lithographic micro-nanostructures, and micro-nanoparticle.

Keywords: digital holographic microscopy, surface plasmon microscopy, near-field optical imaging, resolution improvement

Topic: SS3: Advances in digital holography techniques
Abstract No: 15532

High-speed 3D particle tracking using neuromorphic digital holography

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Content

Digital holography is a promising technique for three-dimensional (3D) particle tracking. However, its performance in high-speed applications is limited due to low temporal resolution and significant data redundancy. In this work, we propose to utilize neuromorphic imaging in digital holography for high-speed 3D particle tracking. Neuromorphic imaging offers the unique capability to detect light changes with high temporal resolution, low latency, and no motion blur. These advantages make it well-suited for detecting light changes caused by fast-moving particles. As a proof-of-principle, we experimentally illustrate a neuromorphic digital holography platform that records the 2D holographic diffraction patterns of moving particles as neuromorphic signals. The recorded neuromorphic holographic data is then processed by developing a decision algorithm for identification and tracking. The experimental results suggest that neuromorphic imaging could be a new paradigm shift in digital holography.

Keywords: Digital holography; particle tracking; neuromorphic imaging

Topic: SS3: Advances in digital holography techniques
Abstract No: 15574

Digital Holography with Deep Learning for Algae Identification and Classification

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Content

Recently, the characterization of marine objects, populations and biophysical interactions have become crucial within the research community. In this study, we leverage digital holographic imaging systems and deep learning networks to classify three distinct types of macroalgae; chlorella, chlamydomonas, and scenedesmus. We employ two different setups and then compare and contrast between the results from both techniques. The integration of holographic imaging holds promise in replacing expensive characterization systems like AFM, x-ray diffraction, and raman spectroscopy, offering a more cost-effective solution. In the first system, we utilize in-line digital holographic imaging to record and reconstruct images of the algae specimens, while the second system explores off-axis holographic interferometer imaging. An essential advantage of holographic techniques is that they do not require intact samples of the specimens for effective object identification. To further enhance the process we combine deep learning algorithms with holographic imaging, capitalizing on the advance computers and IoT capabilities. This combination enables highly effective characterizing and classification of different types of algae. These innovative approaches pave the way for exciting advancement in marine research and monitoring.

Keywords: digital holography, deep learning, algae, biological specimen recognition, interferometer

Topic: SS3: Advances in digital holography techniques
Abstract No: 15615

A multi-image authentication scheme based on the phase-only hologram

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Content

In this paper, a multiple-image cryptographic authentication scheme based on phase-only holograms is proposed. The scheme encrypts multiple images to be encrypted into a phase-only ciphertext. First, computational holograms of original images to be authenticated are converted to phase-only holograms using the Floyd-Steinberg error diffusion algorithm. Second, these phase-only holograms are sampled using sparse representation with the help of random binary masks, which can greatly improve the encryption capacity, i.e., increase the number of multiple images to be authenticated. Finally, the ciphertext containing the information of original images is obtained by scrambling the integration of all sparse phase using the sequence generated with logistic map. The existence of each original image can be verified by calculating the peak nonlinear correlation map between it and its corresponding decrypted result. Most importantly, high security level can be achieved by considering random binary masks and parameters of logistic map as secret keys. Also, the proposed scheme is highly resistant to occlusion and noise attacks, which provide an effective alternative for the related research using computer-generated hologram.

Keywords: Multiple-image authentication;computer-generated hologram;logistic map;

Topic: SS3: Advances in digital holography techniques
Abstract No: 15648

Quantitative Phase Microscopy and Phase Correlation Spectroscopy for Biology

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Content

Label-free imaging of multiple intracellular organelles, as well as the transport or the interaction of the organells, is of great importance for the study of the mechanism of biological processes. In this talk, quantitative Zernike phase-contrast microscopy (qZ-PCM) will first be presented, which features a high spatio-temporal resolution of 245 nm and 250 Hz and strong immunity against external disturbance. qZ-PCM illuminates a sample with an ultra-oblique annular illuminator comprised of an annular LED array and phase modulates the undiffracted component versus the diffracted component via a high-speed SLM. By recording the phase-shifted interferograms between the undiffracted and diffracted components, a quantitative phase image of a transparent sample can be reconstructed. With Qz-PCM, we have captured several important dynamic processes of intracellular organelles, including chromosome duplication in mitosis, mitochondrial fusion and fission, filaments and vesicles' morphologies in apoptosis. Then, two-beam phase correlation spectroscopy (2B-FCS), which is based on the imaging platform of Qz-PCM, will be presented as a novel, label-free analysis approach to measure the dynamics of flowing particles. With 2B-FCS, the flow of (mainly) red blood cells in tail vessels of live zebrafish embryos was investigated. We believe that the investigated imaging platform can be extended to study many biological processes, promoting biomedical research and diagnosis.

Topic: SS3: Advances in digital holography techniques
Abstract No: 15669

Digital holographic reconstruction and generation with unpaired and dual-distance learning models

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Content

Conventional digital holographic reconstruction techniques face problems of prior physical knowledge requirements, time-consuming phase unwrapping algorithms and so on. In recent years, with the rapid development of deep learning, convolutional neural networks have been applied to deal with holographic reconstruction. Here, we present two learning-based frameworks to address reconstruction problems. The first method is an unpaired end-to-end learning approach based on a cycle-generative adversarial network (CycleGAN) for reconstruction and hologram generation. The core cycle consistent loss links two generators together such that the network can transform information between the reconstruction domain and hologram domain respectively, leading to less preparation work for training data. The second approach utilizes two in-line holograms captured with different distances as the network input. By combining the physical imaging model and the neural network together, the object's phase information can be successfully reconstructed without tremendous data and time-consuming training. This “dual-distance learning” method can implement network training and prediction during an iterative optimization. And improved reconstruction quality can be achieved.

Topic: SS4: Advances in Moiré method and its applications
Abstract No: 15530

Microscale strain distribution measurement before and after crack and delamination occurrence in CFRP laminates by multiplication sampling moire method

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Content

Abstract: The multiplication sampling moiré (MSM) method achieves a strong noise-immunity deformation measurement by performing phase analysis of the second harmonic of grating patterns, which surpasses the limitation of the conventional sampling moiré method that produces phase errors when the first harmonic is submerged by the background noise. In this study, the multiplication sampling moiré method was utilized to investigate the interlaminar fracture behavior of a $[\pm15°]_{2s}$ carbon fiber reinforced plastic (CFRP) laminate specimen under different tensile loads. The full-field microscopic strain distribution maps, including the normal, shear and principal strains, were successfully measured on the cross-section of the CFRP laminates with fiber discontinuities. The results show strain distribution characteristics before and after transverse crack occurrence in the matrix resin region of the CFPR laminates, and the changes in shear strain at the interlayer interfaces before and after the emergence of delamination. The MSM method holds promise for evaluating mechanical properties, fracture behavior, characterizing strain distributions and residual stresses in deformation measurements of various structural and composite materials.

Keywords: Multiplication sampling moiré method; Microscopic strain measurement; CFRP laminates; Interlaminar fracture; Transverse crack

Topic: SS4: Advances in Moiré method and its applications
Abstract No: 15531

Validating the Efficacy of Deformation Distribution Measurement in CFRP Laminates during Three-Point Bending using the Sampling Moiré Method

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Content

The damage behavior of carbon fiber reinforced plastics (CFRP) is highly complex due to the overlapping of various damage forms. To elucidate this deformation behavior, it is crucial to evaluate the micro-scale deformation distribution before the occurrence of each type of damage. The sampling Moiré method has been recognized as an effective experimental technique for analyzing such deformation behavior. In this study, we used the sampling Moiré method to calculate the micro-displacement distributions of $[\pm 45°]_{4s}$ CFRP laminates during a three-point bending test under microscopic observation. Additionally, a finite element model was created under the same conditions to compute the displacement distribution using the finite element method. A comparison of the displacement distributions obtained from both experimental and simulation methods confirmed their consistency. The simulation results also revealed the difference in CFRP displacement distribution characteristics with and without interlayer resin.

Keywords: Microscale deformation, CFRP laminate, Sampling Moiré method, Finite element method

Topic: SS4: Advances in Moiré method and its applications
Abstract No: 15533

The application of the moiré method to defect detection and strain imaging in Si single crystals

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Content

Defect detection is crucial to the manufacture and evaluation of materials, it is still a great challenge to detect crystal defects in a large field of view so far. This paper introduces the two-dimensional digital multiplication moiré method which mainly uses digital image processing technology to detect point defects in crystal structure visually. A hybrid strain method is also introduced to calculate the strain distribution and the defect location coordinates of a lattice structure. We mainly focus on the applications of this method for defect detection and strain measurement in Si single crystals after electron beam damage. The hybrid strain distribution in Si single crystals is measured, and the point defects are detected. After enlarging the atomic structure of the point defects, the shapes of point defects are visualized. The application of the moiré technique to point defect detection in Si single crystals described in this paper also lays an important foundation for defect visualization and strain mapping in the crystal structure of other materials.

Keywords: multiplication moiré method, defect detection, strain imaging, application, Si single crystals

Topic: SS4: Advances in Moiré method and its applications
Abstract No: 15567

Sampling moiré method and its application in 2D/3D deformation measurement

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Content

The Sampling Moiré (SM) method enables digitization and automation of moiré generation and phase analysis. In recent years, due to its efficiency and robustness, this method has been widely employed for real-time deformation field measurement in multi-scale structures. In this study, we report the progress of 2D/3D SM at the Photomechanics Lab. Tsinghua University, and relative application to mechanical behavior of AM manufactured materials and structures.

For 2D measurements, we proposed a direct Sampling Moiré method which can complete deformation measurements based on a single image of the specimen grating under scanning electronic microscope (SEM). In addition, we proposed an orthogonal Sampling Moiré (OSM) method which is capable of simultaneously measuring the phase fields in both directions of the orthogonal grating with higher accuracy.

As for 3D measurements, we introduced a binocular vision projection Sampling Moiré method and a 3D Sampling Moiré (3D-SM) method. The former method does not require grating fabrication, facilitating efficient measurement of the 3D morphology of object surfaces. And the latter method can realize the three-dimensional deformations measurement of the measured object. The accuracy analysis demonstrates that the 3D-SM method possesses the measurement accuracy which is comparable to that of the 3D-DIC method, yet with faster computational speed and higher noise resistance. Furthermore, we applied the 3D SM method for in-situ monitoring of DED additive manufacturing, providing real-time results of the 3D morphology and deformation during manufacturing process. Through this research, the SM method has demonstrated its extensive potential for real-time 2D/3D deformation measurements.

Keywords: sampling moiré; 3D measurement; binocular vision; additive manufacturing

Topic: SS4: Advances in Moiré method and its applications
Abstract No: 15585

TEM Moiré method and its application

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Content

Moiré patterns are common in our daily life and often occur when two periodic lattices with similar periodicities overlap with each other. The Moiré phenomenon is omnipresent also at the nano-scale, which is a powerful tool for the generation of micro- and nano-scale patterns and supperlattices. Studies of various nano-materials and nano-devices are conducted using electron microscopy and Moiré method, such as atomic force microscopy, laser scanning confocal microscopy, scanning electron microscopy, and scanning tunneling microscopy. In most cases, the observed Moiré can all be called scanning Moiré, where the reference lattice is the scanning line. Moiré patterns form between the interference of the surface structure of the tested sample and the scanning line of different microscopy. Transmission electron microscopy (TEM) is also popular and widely used for the characterization of materials in nano-scale. In the conventional TEM images, Moiré patterns will appear simultaneously with the material lattice in a proper condition. It is the lattice in different layers of the tested sample in thickness direction overlap with each other. In numerous literatures, TEM Moiré patterns were used for qualitative analysis of materials properties instead of quantitative analysis. However, quantitative analysis in nano-scale measurement is of great importance in understanding the materials' properties more detail and almost all those articles related to TEM Moiré did not have any quantitative measurement, like displacement/strain or stress measurement. In this work, we intend to talk about the TEM Moiré method and its application.

Keywords: TEM moire; inverse; TBC; Ni-based supperalloy

Topic: SS7: High-accuracy optical deformation measurement of large engineering structures
Abstract No: 15503

Accuracy Analysis of Stereo Calibration Methods with Large Field of View

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Content

Camera calibration is a crucial step for large-scale visual deformation measurement of structures. Although various methods have been proposed to calibrate the intrinsic and extrinsic parameters of cameras with a large field of view, their impact on the measurement accuracy of full-field deformation remains unclear. In this paper, we calibrate the accurate intrinsic and extrinsic parameters of stereo cameras by combining the strengths of different methods, including classical Zhang's calibration, Zhang's calibration considering calibration object quality, improved separated-parameter calibration method, and calibration based on photogrammetry. It is worth exploring whether joint optimization of intrinsic and extrinsic parameters is necessary when the intrinsic parameters of the camera are accurately calibrated. We analyze the influence of calibration parameters on deformation measurement through translation experiments and length replication experiments.

Keywords: binocular vision; camera calibration; large FOV

Topic: SS7: High-accuracy optical deformation measurement of large engineering structures
Abstract No: 15537

Bridge deflection measurement by drone aerial photography using the sampling moire method

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Content

Accurate deflection measurement is vital in evaluating the structural integrity of transportation infrastructures, with bridges being fascinating. In this study, we propose a novel image stabilization technique integrated into the sampling moire method, which leads to a dependable approach for measuring bridge deflection through drone aerial photography. Our experimental verification entailed conducting drone tests on an actual bridge, utilizing a passing test vehicle, and the results showcased deflection measurements comparable to those obtained through conventional methods. This newly developed technology eliminates the need for ground-fixed cameras mounted on tripods, thus enabling precise deflection measurement at the millimeter level for bridges in challenging environments, including marine and mountainous areas.

Keywords: Sampling moire method, Deformation measurement, Phase analysis, Drone camera, Bridge inspection

Topic: SS7: High-accuracy optical deformation measurement of large engineering structures
Abstract No: 15560

Target based multi-camera stereo digital image correlation: calibration and registration

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Content

The multi-camera stereo digital image correlation (MS-DIC) method has received more attention as a non-contact technique for measuring high-spatial-resolution deformation of structures at various scales. Target based MS-DIC method relies less on calibration accuracy and has more flexible camera placement capabilities. However, the overlapping area between two stereo cameras often has inconsistent measurement results. In the proposed method, feature points are introduced in the common field of view between two stereo-cameras to calibration assistance. The positions of the feature points in the camera are constructed with polar constraints. The cost of this will be combined with the cost of Multi-camera calibration, which ultimately optimized using bundle adjustment(BA). The experimental results show that the proposed method can effectively improve the accuracy of registration and full-field displacement measurement.

Topic: SS7: High-accuracy optical deformation measurement of large engineering structures
Abstract No: 15571

Full-field deformation measurement of large wing structure based on the multi-camera network with non-overlapping fields of view

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Content

Measuring the full-field deformation of aircraft wings accurately is a challenging task that needs to be addressed in aircraft research, testing, and service. Among various methods, vision measurement has the advantages of simple equipment, wide usability, high precision, and non-contact measurements. Therefore, it has become a key focus in the field of aircraft wing deformation measurement. However, existing techniques based on binocular vision sensors may not be sufficient for large-sized and complex-shaped wing structures. This is because such structures require both a large measuring range and high precision simultaneously, which poses a challenge for dual-camera vision measurement. To overcome this limitation, a multi-camera network vision system is presented in this study. Firstly, a systematic scheme to measure the full-field wing deformation is developed for the structure static test of large aircraft. Then, a parameter-free circular target detection method is proposed to improve the accuracy and recognition robustness under complex imaging conditions such as underexposure, large perspective distortion, and background interference. In addition, the adjacent stations of the stereo cameras in the multi-camera measurement system do not share an overlapping field of view because there are a lot of environmental restrictions. Therefore, a global calibration method for multiple cameras with non-overlapping fields of view based on multi-view geometric constraints is presented to achieve the coordinate unification. Finally, an actual static load test based on a wing with the span of 10 m was carried out to verify the proposed system and scheme.

Keywords: full-field deformation, large wing structure, videometrics, non-overlapping fields of view, global calibration.

Topic: SS7: High-accuracy optical deformation measurement of large engineering structures
Abstract No: 15603

Simulation and experimental analysis of the precision for the standardized calibration

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Content

Camera calibration is of vital importance in the high-precision measurements. In order to improve the precision for the standardized calibration, it is proposed a simulation and experimental analysis method in this abstract. Through the numerical simulation experiment, we analyze the relationship between the calibration precision of single and stereo cameras and the rotation angle of calibration board, the number of the calibration images. In order to simplify and standardize the calibration process, we manufacture an automatic calibration device, which can achieve automatic and quantitative three-axis rotation. This device extremely simplified the tedious calibration process.

Keywords: Camera calibration; high-precision measurements; Numerical simulation; Automatic and standardized calibration;

Topic: SS7: High-accuracy optical deformation measurement of large engineering structures
Abstract No: 15624

Camera Array based Super Spatio-temporal Resolution Videometrics for Deformation Measurement of Large Structures

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Content

Nowadays the videometrics method plays an important role in motion and deformation measurements of complex large-scale structures. However, it faces challenges in high-accuracy/high-speed measurement in a large field of view. The measurement resolution gets lower when the observation range gets larger. The faster the acquisition speed is, the lower the image resolution is, and with low signal-to-noise ratio worsens the algorithm performance, the measurement resolution is lower. Camera array based videometrics with super spatio-temporal resolution seems to be a good way to solve these problems.

This study presents some research on camera array based videometrics, mainly on how to achieve super spatio-temporal resolution measurements with non-coaxial optical array or coaxial optical array: 1) A super-resolution imaging of subpixel dislocation was realized by non-coaxial optical camera array which can improve the resolution of the acquired image, and then improve the deformation analysis accuracy; 2）A multiple image concentration optimization method based on coaxial optical array is developed to improve the measurement resolution; 3) An Image acquisition and spatial-temporal fusion method based on coaxial optical array with different frame rates and resolutions is developed to achieve high spatio-temporal resolution measurement. Finally, some applications are introduced for large structures measuremen

Topic: SS7: High-accuracy optical deformation measurement of large engineering structures
Abstract No: 15658

Adaptive fringe projection moiré method for large structure morphology measurement

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Content

Optical 3D morphology measurement technology utilizes different optical methods to achieve measurement, which has advantages such as non-contact and nondestructive. Due to the diverse measurement principles, various optical 3D morphology measurement technologies have different measurement ranges, accuracy, and application scenarios. The moiré pattern has been widely used due to its ability to amplify the grating deformation without distortion and the modulation effect of the object's surface morphology. The projection moiré method has the potential to achieve high-precision measurement in the entire field precisely. However, the existing projection moiré methods still have problems, such as significant differences in measurement resolution and accuracy between different regions, which in turn affect the accuracy of full-field measurement and the reconstruction effect of complex surfaces. Therefore, we propose an adaptive projection moiré method, which develops adaptive moiré methods and system calibration methods by establishing imaging and moiré models to improve the resolution and accuracy of full-field measurements.

Topic: SS8: High-precision optical measurement
Abstract No: 15581

Spectral mechanical investigation of the elastic interface between a MoS2/graphene heterostructure and a soft substrate

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Content

Van der Waals heterostructures of two-dimensional materials (TDMs), such as graphene/MoS_2 heterostructures, have broad application prospects. Therefore, it is still essential to investigate the interfacial mechanical behavior and the strain transfer mechanism in TDM heterostructures and between TDMs and flexible substrates under deformation. In this work, a MoS_2/graphene heterostructure was assembled on a formvar/polydimethylsiloxane (PDMS) substrate. Spectral mechanical experiments were conducted via Raman and photoluminescence spectroscopy under equiaxial loading to obtain the strain state of graphene and MoS_2. The experimental results showed that the codeformation assumption, applied as a basic rule in most relative work, was incorrect. This assumption proposed that the substrate and two-dimensional material shared the same strain before interface slip. However, the experiments showed that the strain of the two-dimensional material was much less than that of the flexible substrate and that the former maintained a fixed proportion with the latter. Based on this phenomenon, a strain transfer model of the finitely elastic interface was proposed by simplifying the interfacial connection of the TDM film and the substrate as numerous shear springs. The strain transfer mechanism from the substrate to the two-dimensional material was described, and the strain transfer coefficient was introduced to qualify the strain transfer efficiency before interfacial slipping. The analysis showed that this model can explain the experimental results in this work and other published relative works. Based on the model, the interfacial competition mechanism in the MoS_2/graphene heterostructure was revealed in this work.

Keywords: Two-dimensional material heterostructure; Strain transmission model; Finitely elastic interface; Strain transmission coefficient; Flexible substrate;

Topic: SS8: High-precision optical measurement
Abstract No: 15522

Smoothed-truncated-sine(STS) Pattern for Accuracy Improvement in Sinusoidal Fringe Projection Profilometry

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Content

Sinusoidal patterns are widely employed in fringe projection profilometry for high-accuracy measurements. However, in practice, random factors such as camera noise will seriously affect the accuracy of sinusoidal patterns. This paper presents a smoothed-truncated-sine (STS) pattern design method that can achieve higher accuracy than sinusoidal patterns under the same noise. By insensitive harmonic modulation, the STS pattern can achieve a higher signal-to-noise ratio (SNR) to reduce the random error and maintain the amplitude of sensitive harmonics low to restrain the systematic error. First, the error mechanism is analyzed, and the error model is established for the phase shifting algorithm, taking into account the resistance of the phase shifting algorithm to part of high-order harmonic errors. Second, a STS pattern is proposed and optimized based on the error model. The parameters of the STS pattern are optimized to achieve a high SNR and a small phase error, resulting in improved performance of the multiple-step phase shifting algorithm, especially when the number of steps is large. Simulations and experiments demonstrate that the proposed method achieves higher accuracy than sinusoidal patterns and that the maximum error reduction ratio exceeds 20% if the number of steps is sufficiently large in sinusoidal fringe projection profilometry.

Keywords: Fringe projection profilometry; sinusoidal pattern; smoothed-truncated-sine pattern; camera noise; high-order harmonic.

Topic: SS8: High-precision optical measurement
Abstract No: 15523

A Weighted Least Squares Algorithm for Wrapped Phase Retrieval in Sinusoidal Fringe Projection Profilometry

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Content

The sinusoidal fringe projection profilometry (FPP) is a promising 3D shape measurement technique applied in industrial inspection owing to its noncontact, high-precision, and low-cost characteristics. The sinusoidal FPP employs the least squares (LS) algorithm as the fundamental method for recovering the wrapped phase distribution from the recorded fringe patterns. However, the intensity noise level of the fringe pattern acquisition process varies and does not satisfy the assumption of constant variance in the LS algorithm. As a result, the LS algorithm is essentially not appropriate to existing FPP systems and can only obtain suboptimal phases. Therefore, the wrapped phase calculation method should be optimized according to the nature of the random noise. To this end, a weighted least squares (WLS) algorithm is proposed in this paper to achieve effective suppression of heteroscedasticity and obtain the phase results with minimum variance. In contrast to the LS algorithm, which treats each intensity equally, the WLS algorithm assigns different weights over intensities to counterbalance the change in the variance of noise. The weights are determined according to the variance properties of noise in the measurement system. Simulations and experiments demonstrate that the proposed method effectively improves the accuracy of wrapped phase measurement in sinusoidal fringe projection profilometry.

Keywords: Fringe projection profilometry; least squares; weighted least squares; camera noise; heteroscedasticity

Topic: SS8: High-precision optical measurement
Abstract No: 15550

High-precision deflectometry: challenges and prospects

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Content

Phase measuring deflectometry is a powerful measuring technique of complex optical surfaces. Its measurement accuracy is comparable with conventional interferometry, but with higher flexibility, stability and efficiency. The relative positions between the camera, workpiece and screen are of significance because it directly determines the reliability of the measurement.

This talk systematically investigates the main issues governing the measurement accuracy of deflectometry, namely the camera model inconsistency, the height-slope ambiguity, the angle-position uncertainty and rank-deficiency. A flexible camera model and an automatic calibration method are developed, and a specially designed camera lens with its stop set outside can improve the compactness of the system. The geometrical pose and location of the workpiece are solved by minimizing the re-projection error of ray tracing, and an automatic positioning method is proposed by combining the bundle adjustment and Gaussian process regression. The phase error resulting from the defocus and aberrations are compensated by forward convolution. The hybrid-reflective-refractive phase measuring deflectometry is also development for measuring transparent lenses. The measurement accuracy of freeform optics can be improved up to 20 nm RMS from microns, which can find widespread applications in the efficient and precision inspection of advanced optical components.

Keywords: optical measurement, deflectometry, calibration, phase error

Topic: SS8: High-precision optical measurement
Abstract No: 15607

A chromatic confocal bimodal signal pattern based on offset slit filtering

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Content

The quality of the spectrum signal output from chromatic confocal line sensors is generally poor due to the crosstalk effect and the noise of the area CMOS. This results in a significant discrepancy of the precision. Therefore, improving signal quality to enhance sensor precision is a major focus of CCLS research.
In this paper, a chromatic confocal bimodal signal pattern based on offset slit filtering is proposed to optimize the feature representation of the spectrum signal. By radially offsetting the slit filter window before spectral analysis, we intercepted the spectral information of the edge region of the feedback spot and get the spectral power distribution (SPD) with bimodal feature. Compared to the center region, the signal intensity in the edge region is weaker, but the bimodal feature is easier to locate which facilitates the extraction of high-precision distance information.
With our self-developed CCLS, the full width at half maximum (FWHM) of the peak features in the bimodal signal pattern is less than 50% of the peak features in the traditional unimodal signal pattern. The precision calibration experiments show that the bimodal signal pattern can achieve 0.6μm precision over 4mm range, which is a 40% improvement compared with traditional unimodal signal pattern with the same hardware configuration.

Keywords: optical measurement; confocal line sensors; chromatic confocal; spectral analysis; high precision measurement

Topic: SS8: High-precision optical measurement
Abstract No: 15608

Simultaneous thickness and refractive index measurement based on chromatic confocal aberration compensation

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Content

In the traditional model of transparent plate measurement, due to the coupling of thickness and refractive index, one parameter must be measured while the other is acquired. Meanwhile, axial spherical aberration occurs when the chromatic confocal sensor (CCS) measures the thickness of the transparent plate, which in turn leads to the measurement error. To solve these problems, we propose a new measurement model that simultaneously obtains the thickness and the refractive index of transparent plate. Axial spherical aberration is considered in the new model and solved using Newton's iterative method. The experimental devices consist of a motor to move the CCS and a reflector placed behind the sample to obtain peak signals at different surfaces. Experimental results show that the model can achieve an average thickness measurement error of ±0.5μm and an average refractive index measurement error of ±0.011. Compared with traditional measurement models, the new model expands the application of the CCS, for example, by using the CCS for on-line inspection of film thickness and refractive index, such as new energy vehicles, flexible displays, biomedicine, etc.

Keywords: chromatic confocal sensor; transparent plate; thickness and refractive index

Topic: SS9: Imaging through scattering media and non-line-of-sight imaging
Abstract No: 15462

Exploring the range of optical memory effect by deep learning

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Content

Among the various methods for imaging through scattering media, the speckle autocorrelation imaging method based on Optical Memory Effect (OME) has gained significant attention for its non-invasive single-shot imaging capability through a scattering layer. However, the imaging range of this method is limited by OME. This paper presents a physics-informed deep learning strategy that establishes relationships among different linearly-shift-invariant subsystems based on OME to customize different OME regions. By leveraging the feature extraction capabilities of deep learning, the proposed approach recovers sidelobes from the scattered autocorrelation pattern of several OME regions. Furthermore, a phase recovery algorithm is employed to achieve object reconstruction. Through three sets of experiments, the proposed method demonstrates its generalization ability to unknown object spacing, unknown scattering media, and unknown object types. In the future, the approach can be extended to more complex scenarios, including imaging of complex objects, larger fields of view, and dynamic scattering media.

Keywords: optical memory effect, deep learning

Topic: SS9: Imaging through scattering media and non-line-of-sight imaging
Abstract No: 15463

Fingertip OCT Image Acquisition and Enhancement

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Content

Optical coherence tomography (OCT), as a non-destructive and high-resolution in vivo imaging technology, has been adapted in fingertip biometric acquisition. It measures on and beneath skin fingertip information as 3D volume data, containing the internal fingerprint, sweat pores and glands. Even though it has become a powerful tool for fingertip information acquisition, speckle noise in OCT images can cover sweat glands and blur tissue contours making extraction difficult. Although traditional denoising methods can remove speckle noise to some extent, they can cause unclear tissue information and structural loss due to smearing and excessive smoothing. This paper proposes a OCT image enhancement method for fingertip data based on generative adversarial network. A paired dataset generation strategy is proposed to extend a small number of manually enhanced groundtruth into a high-quality paired dataset. Then, an improved image enhancement neural network is proposed, which adds a perceptual loss function to increase the weight of structural information in the original image. Experiments show that the proposed enhancement method can effectively remove speckle noise while restoring structural information of finger tissue.

Topic: SS9: Imaging through scattering media and non-line-of-sight imaging
Abstract No: 15469

Modelling multiple scattering of polarized light with random matrices

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Content

Multiple scattering of light in random media is detrimental to information transfer in a wide variety of situations, such as in astronomy, remote sensing, and biomedical imaging. When coherent light passes through a random medium, the scattered field is typically depolarized and its spatial intensity distribution exhibits a complex speckle pattern, within which information about the incident field is lost. Owing to its stochastic nature, random scattering is typically studied using statistical methods. Random matrix theory, in which the scattering matrix is randomly sampled from a matrix ensemble, has been fruitful at uncovering universal properties of disordered systems, such as the existence of highly transmitting open eigenchannels. Traditional models, however, neglect the vectorial properties of light and are thus unable to account for polarization phenomena, such as the circular polarization memory effect.

We present a random matrix based simulation method for generating random vectorial scattering matrices whose statistical properties resemble those of realistic scattering media. With our method, we may propagate arbitrary wavefronts through random media and analyse the statistical properties of the scattered fields, such as the degree of polarization and mean scattered intensity. We may also analyse the statistical properties of the ensemble of random media, such as the mean Mueller matrix and the polarisation statistics of the transmission and reflection eigenchannels. In our talk we review our past work and discuss recent advancements.

Keywords: random scattering; random matrix theory; scattering matrix; polarised light; multiple scattering

Topic: SS9: Imaging through scattering media and non-line-of-sight imaging
Abstract No: 15580

Multi-strategy close range 3-D shape measurement in turbid water based on structured light

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Content

Underwater three-dimensional (3-D) measurement plays an important role in ecological protection, archaeological pieces and seabed reconstruction, etc. Structured light-based methods achieve accurate 3-D measurement by simply projecting structured patterns. However, in turbid water, due to the absorption and scattering of light, scattering caused noise is introduced, thus resulting in low 3-D measurement accuracy. In this paper, a multi-strategy close range 3-D measurement method based on structured light is proposed for accurate 3-D shape measurement in different water turbidity conditions. Two typical techniques of structured light-based 3-D shape measurement techniques, fringe projection profilometry (FPP)and single-pixel imaging-based metrology (SIM), are selected to reconstruct the 3-D shape of underwater object. For low water turbidity conditions, we introduce a Hilbert transform-based method to compensate the scattering error in FPP. For water with higher turbidity, an end-to-end fringe image enhancement algorithm based on deep learning is proposed. The Fringe Pattern Enhancement Convolutional Neural Network (FPENet) is used to enhance the image quality of the fringe image captured in turbid water and reduce the phase error. As a result, the phase error can be reduced by about 50%, which significantly improvs the measurement accuracy of underwater FPP. For high water turbidity conditions, we introduce SIM for accurate underwater 3-D reconstruction, and propose to use compressed sensing to reduce the measurement time.

Keywords: Underwater close range 3-D measurement; structured light; turbid water

Topic: SS10: Industrial optical inspection and non-destructive testing (NDT)
Abstract No: 15513

Development of a vision system for cast mould defect inspection under extreme high temperature

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Content

Internal surface condition of mould will affect the metalworking product quality after the casting process. Although the defects on the internal surface are always visible to the naked eyes, it is impossible for operator to inspect the condition immediately when the temperature of internal mould has yet cool down from 500°C. Traditional visual inspection devices, such as borescope and laser scanning, cannot keep working when the temperature is beyond 70°C. An automated defect inspection system is essential for accomplishing the task with the challenge of functioning under extreme work environment. Common defects, such as dents, cracks and holes, are required to detect in-situ quality inspection within scheduled production.

In this paper, the development of a vision inspection system which is sufficiently protected by a cooling housing is discussed. The system was designed to provide quality images for defect inspection needs while enduring high temperatures. Optical components including camera sensor and lens were configured to meet the defect detection criteria. Illumination strategy consisting of lighting position and orientation was developed to cover 360° inner surface and accentuate defects in images. The housing protected vision system would be motorized into the mould to user-specified position and capture images with trigger mode. Developed algorithm would process images and output inspection results in the backend. Overall inspection of 2-meter mould could be completed within 100 seconds.

The developed vision system is fast and low-cost, which can be easily implemented on site and provide defect inspection for cast mould with high temperature.

Keywords: defect inspection; camera housing; illumination strategy; trigger mode; image-processing module

Topic: SS10: Industrial optical inspection and non-destructive testing (NDT)
Abstract No: 15650

Use of X-Ray Computed Tomography (CT) of weld spots defects

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Content

Non-destructive inspection of parts via X-Ray Computed Tomography (CT) has widespread use in the manufacturing industry. Inspection of weld spots in parts are often tested using traditional optical means such as optical microscopy for quick results. However, optical microscopy has limitations such as sub-surface defects or fine cracks due to lighting and inspection angle.

For example, black spots appear on weld spots due to the high temperatures. As such, using optical inspection of weld spots can lead to actual defects being dismissed as simple surface defects. In other instances, a scratch on the surface was a crack stemming from the surface. Poor lighting choices and limited angles to inspect these defects further deters accurate classification of defects. Sub-surface defects are also not detectable by such means.

With X-Ray CT, the weld spot can be inspected from all orientations. A completed scan reconstructs a three-dimensional (3D) model of the sample that can be inspected slice by slice along each of the cardinal directions at high resolutions, the sub-defects can be seen in these slices. Despite the benefits of using X-Ray CT, there are drawbacks such as longer scan times, reconstruction artefacts, material's X-ray absorptivity.

The paper will discuss the benefits of using X-ray over using optical inspection as well as the limitations of using x-ray CT and some ways to circumvent them. At the end of the paper, we will have a better understanding of when one can consider using X-ray CT as well as how to get the best results.

Keywords: X-ray, Computed Tomography, Non-destructive testing

Topic: SS10: Industrial optical inspection and non-destructive testing (NDT)
Abstract No: 15477

Exploitation of Industrial X-ray Computed Tomography for Surface Metrology of Metallic Additively Manufactured Parts

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Content

Industrial XCT has recently attracted extensive attention in geometrical metrology due to its ability to measure both external and internal surfaces non-destructively. This advantage makes XCT a promising technology for inspecting additive manufacturing (AM) parts with complex geometries, typically inaccessible via traditional tactile and optical methods. Particularly, XCT can capture various 3D surface topographical features specific to AM, including particle features, undercuts and overhangs, surface cracks, and open porosity - a distinct trait of AM surfaces. Understanding the impacts of these features aids in predicting the performance of AM parts, such as fatigue, heat dissipation, and osseointegration. This paper summarises our recent research work in exploiting industrial XCT for surface metrology of metallic AM parts, covering performance benchmark of XCT by comparing it to the focal variation microscope, assessment of XCT blurring effect via the surface amplitude transfer function, reconstruction of the point spread function associated with the X-ray focal spot, iterative deconvolution to improve the metrological structural resolution of XCT, and 3D surface characterisation techniques to address AM freeform and re-entrant topographical features.

Keywords: X-ray Computed Tomography; Surface metrology; Additive manufacturing;

Topic: SS10: Industrial optical inspection and non-destructive testing (NDT)
Abstract No: 15481

An initial study on using X-ray computed tomography to measure the surface roughness of additively manufactured metal lattices

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Content

Through the layer wise addition of material, additive manufacturing (AM) processes offer potential advantages including increased geometrical complexity, design freedom and topology optimisation for the manufacturing of products, such as light weight lattice structures, not possible with traditional forms of manufacturing. There is growing interest in the implementation of AM lattice structures in many industrial sectors, for example, lattice-based heat exchangers for energy applications, and porous-integrated medical implants designed to promote osseointegration and reduce stress shielding effects. However, due to the nature of AM processes, AM parts often deviate from their intended designs, which can influence functional performance. Thus, quality assurance and performance verification of AM lattices are required for their increased industrial uptake, especially in safety and performance-critical applications. Traditional tactile and optical metrology techniques, such as co-ordinate measuring machines and focus variation microscopes, are insufficient with regards to accessing inner lattice topographical architecture. The undertaken project utilises X-ray computed tomography for the non-destructive metrology of AM lattice structures and aims to develop characterisation methods to assess lattice dimensions and surface roughness. Current work has comprised of assessing lattice deviations to CAD data as well as analysis of surface roughness across varying regions of a lattice structure.

Keywords: AM, XCT, Lattice

Topic: SS10: Industrial optical inspection and non-destructive testing (NDT)
Abstract No: 15500

Automated Visual Inspection System for Visible Particulates in Injections

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Content

In pharmaceutical manufacturing, foreign particles may be present in the injection containers. Therefore, a stringent inspection must be conducted, as it directly impacts the quality of pharmaceutical injection products. With the recent trend of industrial automation and digitalization, there has been a significant increase in the implementation of automated visual inspection (AVI) systems. To inspect particles in the liquid formulation, the containers need to be rotated at speeds of up to 6,000 RPM. However, the generation of bubbles during high-speed rotation poses a significant challenge to the AVI process, leading to a high rejection rate. Consequently, manual inspection persists as the industrial standard, despite its drawbacks of inconsistency and labor-intensiveness.

This research introduces a novel AVI system featuring high resolution, low false rejection rates, and in-line inspection capabilities. Its unique automation design allows for longer inspection times on containers, enabling the generation of high-resolution images while maintaining an industrial throughput of up to 36,000 containers per hour. The specially designed lighting module can detect both light-absorbing and light-reflecting particles, and by utilizing pulsing with overdriving LEDs, the cameras can freeze images of floating particles. To accurately differentiate between bubbles and transparent particles such as glass and silicon, an AI-assisted inspection algorithm has been developed.

Experimental results demonstrate the performance of the developed AVI system, achieving an accuracy rate of over 95% in classifying bubbles and foreign particles. The robust detection and classification of particles facilitate prompt feedback to the production process, thereby enabling continuous improvement.

Keywords: visual inspection; particle detection; parenteral injections; image processing; deep learning

Topic: SS10: Industrial optical inspection and non-destructive testing (NDT)
Abstract No: 15544

Three-dimensional height measurement with an improved 3D camera

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Content

Three-dimensional (3D) height measurement plays a pivotal role in ensuring the production of reliable parts in precision engineering and semiconductor industries. This paper proposes a 3D camera by reconstructing height information from different perspectives captured in one shot. It then reconstructs the height using defocus cues. It is shown that the technique can measure the height information of features in semiconductor components effectively.

Keywords: 3D vision

Topic: SS10: Industrial optical inspection and non-destructive testing (NDT)
Abstract No: 15638

Transformer-based Smart Inspection for Agricultural Products via X-Ray Images

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Content

The supply chain of agricultural products is intricately linked to the daily lives of people. In light of rising import and export quantities, the need for a prompt and efficient inspection system has become increasingly pressing. Without opening baskets and manually sorting, a smart inspection scheme is designed in this work leveraging X-ray images and transformer neural network. Due to its penetrating capabilities, X-ray enables a direct examination of agricultural products within a basket, a task that optical devices are unable to accomplish. Taking into account the varying shapes of agricultural products, we introduce a transformer-based deep neural network for category identification. Additionally, a dataset augmentation process is developed inspired by computed tomography generating 19768 X-ray images. Through experiments, the proposed smart inspection scheme is proven to be feasible and works efficiently. The identification accuracy for both single-type and mixed-type agricultural products on the established dataset exceeds 90%.

Keywords: Agricultural Product; Inspection; X-ray images; Transformer; Neural Network

Topic: SS12: Micro/Nano-Mechanical measurement and characterization by optical/spectral methods
Abstract No: 15540

Evolution of diffusion and induced stress and its effect on the lithium-storage performance of graphite electrode

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Content

The diffusion process and stress play important roles in the lithium storage performance of electrode materials, which directly affects the electrochemical performance of lithium-ion batteries. In this work, the origin and evolution of diffusion and electrochemically induced stress of the graphite electrode are investigated by in situ experiments and simulations. An optical acquisition system with an electrochemical battery as the core is constructed. Using the electrochromic characteristics of graphite electrodes, the phase evolution information is displayed in real time, and Li concentration inside the graphite electrode is quantified. According to the experiment results, an electrochemical-mechanical coupling model is developed and verified by the experimental Li concentration, and the spatiotemporal evolution of the potential，Li concentration and stress during the diffusion process is characterized. The results show that Li intercalation leads to compressive stress, which presents a gradient distribution along the Li diffusion path and exhibits a 'piecewise' nonlinear growth trend with increasing lithiation time. In addition, as the potential decreases, the stress increases from slow to fast relative to the Li-concentration increase, showing the characteristic of stages. The influence of stress on the lithium-storage performance is discussed using the local lithium-intercalation rate and phase-interface migration speed as the key parameters. The lithiation mechanism is analyzed from the perspective of the energy, finding that the two factors cause the slow diffusion in the late stage of lithiation, thus affecting the actual lithium-storage performance. This study enhance the understanding of electro-chemo-mechanical coupling mechanism and provide guidance for enhancing stress-regulated battery performance.

Keywords: Graphite electrode; Diffusion process; Electrochemically induced stress evolution; Electrochemical–mechanical coupling model; Stress effect; Lithium-storage performance;

Topic: SS12: Micro/Nano-Mechanical measurement and characterization by optical/spectral methods
Abstract No: 15547

Measurement of geometric and mechanical parameters for fatigue microcrack based on tracking platform

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Content

In order to realize full-field high-resolution multi-scale deformation measurement, a multi-scale digital image correlation measurement system is proposed which composes of a three-axis electric translation platform, 4 high-resolution cameras, 3 telecentric lenses with different magnification and 1 microscopic lens. The deformation measurement can be realized from macro to micro scale by using this measuring device. The experimental results show that the tracking and observation of arbitrary micro-region can be realized by using the proposed measurement device placed on a high-precision 3D controllable tracking platform. The calibrated measuring system can arbitrarily switch the measuring scale of the observation area to achieve the required measurement accuracy and observation requirements. Finally, the surface texture of corroded bainite steel was measured by digital image correlation. The measuring system has a good application prospect for the study of geometric and mechanical behavior of fatigue microcrack.

Topic: SS12: Micro/Nano-Mechanical measurement and characterization by optical/spectral methods
Abstract No: 15652

New photomechanics methods in characterizing high-temperature fatigue crack growth behavior of nickel-based superalloys

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Content

The high-precision measurement of high-temperature deformation field and its quantitative correlation with fatigue fracture behavior are key scientific issues in high-temperature fatigue investigations based on photomechanics methods. Herein, key techniques advances such as parametric high-temperature deformation carrier fabrication, single-lens 3D digital image correlation system calibration, the synchronization and match of high-temperature fatigue testing-optical measurement, and automated crack tip localization with massive images will be introduced respectively, and then focusing on the new methods of characterizing the crack closure effect based on the displacement field. By establishing the correlation between crack tip deformation field and multiple important fatigue fracture parameters of (additively manufactured) polycrystalline/single crystal nickel-based superalloys, such as the stress intensity factor and crack opening load, the automated analysis of the whole process of high-temperature fatigue crack growth behavior is realized.

Topic: SS12: Micro/Nano-Mechanical measurement and characterization by optical/spectral methods
Abstract No: 15657

Uses of image features in digital image correlation for deformation measurement

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Content

Digital image correlation (DIC) is a widely adopted non-contact technique for deformation measurement. By tracking the motion of speckles in the image pair collected before and after deformation of object, displacement or strain field at various scales can be determined for further analysis of mechanical responses. Recent study shows that image features can be employed to enhance the capability of digital image correlation to measure large and complex deformation. This talk demonstrates a few interesting uses beyond the reported work, including evaluation of speckle image quality for DIC measurement, automatic optimization of parameters in DIC calculation, and modification of features for processing of binarized images.

Topic: SS13: Optical dynamic measurement
Abstract No: 15476

Modeling of Mechanoluminescent Strain Sensing Mechanisms and Their Application to Vibration Modal Measurements

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Content

The mechanoluminescent (ML) sensor has attracted interest due to its potential for application to strain distribution, crack visualization, and structural health monitoring. It offers full-field strain/stress measurements and has the advantages of easy implementation, non-invasiveness, and low cost. However, knowledge of the mechanism of carrier detrapping owing to mechanical forces remains elusive as it may include one or more complicated processes. Several attempts to use ML sensors for qualitative measurement of stress distribution, but few studies have established mathematical models for quantitative measurement. In this study, we built a real-time measurement system to evaluate the constitutive strain-luminescence relationship of ML sensors. A double-exponential function was applied to describe nonlinear changes in light intensity over time. We used this function to build a model and predict the ML responses under variable loading rate conditions. The results predicted by the model proposed in this paper are in good agreement with the experimental results. On this basis, we successfully obtained the first three orders of strain modes for several beam structures. The study also shows that experimental parameters, such as the exposure time of the camera and the amplitude of excitation, do not affect the validity of this method. The robustness and convenience of the proposed method make it a more efficient technique than prevalent electrical or optical vibrational methods of analysis.

Keywords: mechanoluminescent sensor;Vibration Modal Measurements;Mechanisms;Model;Beam structures

Topic: SS13: Optical dynamic measurement
Abstract No: 15482

Improved Speckle Interferometry Method based on High-Speed Camera and Laser Doppler vibrometers

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Content

In this paper, a new electronic speckle pattern interferometry method is proposed, which does not require vibration isolation of the measured object and can be used for precise in situ deformation measurements. The feature of the method is the combination of a high-speed camera and multiple laser Doppler vibrometers (LDVs) for synchronous measurements. The high-speed camera is used to record and select effective interferograms. By setting the fringe-contrast threshold, interferograms with a high fringe contrast and small in-plane displacements can be screened from multiple images, thereby avoiding the problem of speckle decorrelation and reducing the influence of in-plane displacements. LDVs are used to obtain phase shifts for effective speckle interferograms. Since the motion of the object caused by vibrations is generally considered as rigid body motion, when in-plane displacements are negligible, by fitting the data measured by multiple LDVs of rigid regions, the out-of-plane displacements of the entire plane caused by vibrations can be obtained, which can be used as phase shifts directly. The deformation phase can be calculated by a series of effective interferograms with known shifted phase values. The experimental results show that the method performs well in measuring static and dynamic deformations with high accuracy in vibrating environments.

Keywords: speckle pattern interferometry, laser Doppler vibrometers, in-situ deformation measurements

Topic: SS13: Optical dynamic measurement
Abstract No: 15527

Suppression of speckle noise in laser Doppler vibrometry by signal diversity and dynamic ellipse fitting

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Content

The speckle effect caused by coherent light scattering from rough surfaces modulates the intensity and phase of the interference signal, which results in signal dropouts and phase noise for Laser-Doppler vibrometers (LDV), limiting the accuracy and resolution of LDV. Signal diversity has been demonstrated to significantly suppress the speckle noise in single-point LDV vibration measurements since two or more statistically independent reception channels greatly decrease the probability of speckle noise occurring. In this paper, an orthogonal interferometer based on polarization diversity is presented. We discuss the potential of detecting and correcting the outliers by speckle noise with dynamic ellipse fitting and correction algorithm for orthogonal interferometers. The displacement measurement of LDV is obtained by phase synchronization and fusion of demodulation data from two channels. The conclusion of this article is that signal diversity combined with a dynamic ellipse fitting algorithm is feasible to suppress speckle noise resulting from the periodic movement of the target.

Keywords: Laser Doppler vibrometer; speckle noise suppression; signal diversity; orthogonal interferometer; dynamic ellipse fitting

Topic: SS13: Optical dynamic measurement
Abstract No: 15543

Method for measuring full-field vibration of rotating components using laser and image fusion

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Content

Vibration measurement, particularly mode shape measurement, is an important aspect of structural dynamic analysis. However, vibration measurement of rotating components is very difficult, which affects the development of related major equipment. Scanning laser Doppler vibrometry (LDV) and high-speed digital image correlation have become dominant methods for experimental mode shape measurement. However, these methods have some disadvantages in terms of equipment cost and spatial or temporal performance. an optical de-rotator laser Doppler vibrometer was used to induce stroboscopic digital image correlation for non-contact measurement of the mode shape and operational deflection shape of rotating components. The results show that the proposed method can obtain high spatial resolution mode shapes and operational deflection shape using low-cost single-point LDV and normal rate cameras. Measurement frequency range is much higher than camera capturing rate.

Keywords: Rotating components, vibration measurement, laser Doppler vibrometry, Digital image correlation

Topic: SS13: Optical dynamic measurement
Abstract No: 15623

Research and application of optical heterodyne interferometry with high precision

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Content

For the urgent high -precision measurement requirements，especially long -distance laser vibration measurement, optical component facial shape measurement and system wave measurement, our team has overcome the technologies of Hertz-class and Megahertz-class high -precision phase shift technology, and solve the problems of complexity of the control system caused by traditional mechanical migration, nonlinear and other issues; we also equipped the laser sources with coherent length in hundreds of micrometers' range, which can effectively reduce the stay light that affect the measurement accuracy in traditional surface interferometry based on long coherent laser source. It has the characteristics of fast measurement speed, high measurement accuracy and strong environmental adaptability. On this basis, we have developed a series of instruments such as full-field heterodyne laser interferometer and long-distance laser vibrometers, which have applied to the fields of national plane metrology benchmark, high-end optical equipment development, wafer manufacturing and MEMS component characteristic detection, solving the problems of high-precision vibration measurement, topography measurement and wavefront measurement.

Topic: SS13: Optical dynamic measurement
Abstract No: 15646

Full-field vibration measurement based on a combination of laser and imaging technology

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Content

Vibration measurement is essential to dynamic structural analysis since it can validate finite elements or analytical vibration models. Scanning laser Doppler vibrometry (SLDV) and high-speed digital image correlation have become dominant methods for experimental vibration measurement. However, these methods have their own disadvantages in spatial or temporal performance. This paper proposes a non-contact vibration measurement based on a combination of laser and imaging technology. Our results verify that single-point LDV and normal rate cameras can be used to obtain high spatial resolution mode shape and operational deflection shape. In addition, it can offer full-field high spatiotemporal sampling and high-resolution measurement, which can bypass the bottleneck of vibration measurement hardware.

Keywords: Laser Doppler vibrometer, vibration measurement, temporal data analysis, full-field mode shape measurement.

Topic: SS13: Optical dynamic measurement
Abstract No: 15673

Flexible and high-intensity photoacoustic transducer for contact-free laser ultrasonic inspection

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Content

With the merits of contact-free and in situ inspection, laser ultrasonic technique has been increasingly implemented for evaluating structure integrity. However, the poor signal-to-noise ratio and low amplitude of laser generated ultrasonic signals under thermoelastic regime severely restrict its practical applications. In this work, we propose a method for fabricating flexible, high-intensity and readily transplantable photoacoustic transducer (PAT) comprised of candle soot nanoparticles (CSNPs) and polydimethylsiloxane (PDMS), and utilize it to generate high SNR and amplitude ultrasonic signals for structure inspection. A robotic-arm based layer-by-layer automatic scanning strategy is developed to realize CSNPs deposition with excellent homogeneity, and the optimal thickness of PDMS/CSNPs nanocomposite layer to achieve high SNR and amplitude ultrasonic signal is obtained. The optimized PAT is eventually combined with laser ultrasonic technique to successfully detect the internal defects of large dimensional structures without any damage. Further, the ultrasonic surface wave modulation method based on PAT is proposed and combined with nonlinear wave mixing technique to detect the fatigue crack of a structure. The PATs are optimized to generate narrowband surface wave with high intensity and SNR under the thermoelastic regime. Two modulated laser ultrasonic surface waves are excited on a fatigued aluminum plate to generate nonlinear mixed components, and the ultrasonic responses over the fatigue crack regions are obtained by using a scanning laser doppler vibrometer.

Keywords: Photoacoustic transducer, PDMS/CSNPs nanocomposite, laser ultrasonics, defects detection, Fatigue crack

Topic: SS14: Optical measurement and instrumentation
Abstract No: 15518

Visible wide-angle optical reconnaissance system design with high resolution, low distortion and high relative illumination.

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Content

Wide-angle lenses usually have low relative illumination and high viewing angle distortion. Therefore, in this paper, a single-center objective lens is combined with 500 identical eyepieces and camera to avoid the above two disadvantages. The design method is to use the optical software CODE V to separately design the single-center objective lens, eyepiece and camera, and then splice them one by one into a wide-angle optical reconnaissance system.

Wide-angle optical reconnaissance system consists of a single-center objective lens, 500 sets of eyepieces and a camera with a focal length of about 60mm. Here, the combination of eyepiece and camera is referred to as a micro-camera lens. Because the objective lens and eyepiece are combined into an afocal system, the focal length of the system is determined by the focal length of the camera and the focal ratio of the objective lens and eyepiece.

Finally, the wide-angle lens with a horizontal viewing angle of about 120 degrees and a vertical viewing angle of about 60 degrees with a focal length of about 100mm was achieved by splicing micro-camera lenses. Due to the small viewing angle characteristics of the micro-camera lens, the reduction of relative illumination is avoided, and the single-center objective lens reduces the volume of the system by more than 70%. , it is calculated that within 4 to 6 kilometers, the accurate identification ability of 4 m, 7 m and 10 m ships can reach more than 70%, which can be used for traffic monitoring and stadium dynamic records.

Keywords: (Wide-angle optical reconnaissance system ; Code V ; Micro-camera lenses)

Topic: SS14: Optical measurement and instrumentation
Abstract No: 15545

Phase retrieving by extracting Zernike coefficients from two random phase-shifting interferograms based on deep learning

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Content

This paper presents a method of extracting Zernike coefficients and then retrieving the phase based on deep learning. In the normal interferometry, the phase extraction algorithm is utilized to calculate the wrapped phase according to the registering phase shifting interferograms, and then unwrap it to obtain the phase map. Further, Zernike polynomials are used to fit the phase. The method proposed in this paper uses neural networks to extract 36 terms of Zernike coefficients from two random phase-shifting interferograms, then retrieve the phase based on Zernike polynomials. The method only needs two random phase-shifting interferograms, does not require phase extraction and unwrapping processing and greatly simplifies the computation for phase reconstruction.The paper presents the training processing, and provides the experimental results. The results show that the proposed method can reach high precision and are more suitable for the quick testing for workshop environment.

Keywords: Deep learning; Zernike coefficients extraction; Phase retrieving; Random phase-shifting interferograms

Topic: SS14: Optical measurement and instrumentation
Abstract No: 15546

Fast anti-turbidity underwater topography measurement based on structured light

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Content

Aim at the problems of underwater image degradation caused by water turbidity and light path change caused by multi-media, this paper proposes a fast anti-turbidity method for underwater topography measurement. Firstly, an underwater refraction measurement model based on vertical projection is established to rigorously characterize the nonlinear mapping relationship between the underwater measured surface feature points and the imaging points. Secondly, the multi-line structured light rotation projection mode is designed and the binary encoding reduce the dependence of accuracy on image quality; the measurement efficiency and resolution are improved by the center fast rotation method. Finally, the experimental results show that the method can obtain a measurement result with a shape residual of 1.19 mm for the surface topography of regular objects in the measurement range of 1000 mm. This paper facilitates the expansion of vision measurement systems for engineering probing, 3D morphometry, structural defect detection, and other applications.

Keywords: Structured light; underwater refraction; image degradation; land calibration, fast 3D measurements

Topic: SS14: Optical measurement and instrumentation
Abstract No: 15551

Speckle Pattern Interferometry excited by pulse laser for Crack Size Prediction

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Content

Defect detection is an important part of heritage conservation and speckle pattern interferometry is a common technique for inspecting surface and internal defects. A speckle pattern interferometry coupled with photoacoustic system for non-destructive detection and prediction of different size cracks is introduced and tested. On the basis of photoacoustic effect, ultrasonic waves are generated by pumping a pulsed laser beam to the rear surface of the sample. The ultrasonic waves serve as carrier propagating from the rear surface to the front, thus conveying deformation and crack size information. In order to obtain information about crack size, the front surface is illuminated by a continuous wave laser and the interference is imaged onto the camera in the form of speckle images. After unwrapping phase from interferogram, the maximum phase change during a certain excitation period is used for observing crack size difference and prediction. In this study, the introduced system and method were validated by detecting medium density fiberboards with simulated cracks of different width and depth. Different fringes were compared to indicate crack presence and location and maximum phase change for predicting crack size were proposed and validated.

Keywords: speckle pattern interferometry; crack size prediction; pulse laser excitation

Topic: SS14: Optical measurement and instrumentation
Abstract No: 15552

Zernike Polynomials Fitting of Arbitrary Shape Wavefront

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Content

Zernike polynomials are a complete set of continuous functions orthogonal on the unit circle, commonly used for wavefront fitting and analyzing wavefront properties. Zernike polynomials have the unique properties of orthogonality and normalization within the unit circle, which makes them widely used in wavefront fitting and reconstruction. In addition to circular pupils and circular elements, non-circular shapes such as squares ellipses are usually found in optical systems. For non-circular wavefronts the Zernike polynomials lose their orthogonality, which also leads to coefficient coupling thus affecting the effectiveness of aberration removal. This paper presents the method based on the optimized Gram–Schmidt orthogonalization technique to orthogonalize Zernike circular polynomials over the non-circular region through a series of matrix transformations. The proposed method can obtain Zernike wavefront fitting results for arbitrary shape wavefront without deriving the corresponding set of polynomials. The experiment compares the fitting results of circular, square, and other shapes with the interferometer, wavefront fitting was performed separately using different forms of Zernike polynomials set and compared with the analysis. The fitting of non-circular wavefronts is realized using orthogonal Zernike matrix, which verifies the feasibility of the proposed method.

Keywords: Wavefront fitting; Arbitrary shape wavefront; Zernike polynomials

Topic: SS14: Optical measurement and instrumentation
Abstract No: 15654

Trustworthy deflectometry: from precision to accuracy

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Content

Deflectometry is a powerful measuring technique of complex optical surfaces. It has extremely high sensitivity to surface slopes, but the in most cases, the measurement accuracy can only achieve a level of microns. In this talk, the main limiting factors of the measurement accuracy, namely the camera model inconsistency, the height-slope ambiguity, the angle-position uncertainty, and rank-deficiency are investigated systematically.

Solutions to overcoming these problems are then introduced. A flexible camera model and an automatic calibration method are developed. The geometrical pose and location of the workpiece are solved by minimizing the re-projection error of ray-tracing, and an automatic positioning method is proposed by combining the bundle adjustment and Gaussian process regression. The phase errors resulting from defocus and aberrations are compensated by forward convolution. Finally, spline nodes and regularization terms are set properly to suppress the bias and smoothing errors. The measurement accuracy of freeform optics can be improved up to 20 nm RMS from microns, which have found widespread applications in different fields.

Keywords: optical measurement, deflectometry, calibration, measurement uncertainty

Topic: SS14: Optical measurement and instrumentation
Abstract No: 15668

High precision multi-surface interferometry under non-integer sampling

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Content

Optical components, such as high-precision transparent parallel plates, are extensively employed in optical systems, and their surface topographic parameters are critical to the optical performance. The difficulty of multi-surface measurements is that the interferogram contain a superposition of the interferometric signals from each surface. The core problem to be solved here is how to extract the initial phase of surface topographic from the superimposed interferograms. In multi-surface measurements, the demodulation of phases relies on the frequency of each interference signal, which is suffer from the cavity length and the optical thickness of the measured plate. In order to accurately obtain the signal frequencies and demodulate the initial phases of the measured surfaces simultaneously. It proposes a time domain parameter estimation algorithm (TDP). The developed TDP considering the influence of the Gaussian noise on the captured interferograms, the signal frequencies are obtained under non-integer sampling. Comparison of the obtained results of the frequency solution and the accuracy of wavefront reconstruction shows that the developed TDP is better than the fast Fourier transform.

Topic: SS14: Optical measurement and instrumentation
Abstract No: 15672

Development of optical measurement techniques for large aperture optics applied in high power laser systems

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Content

The giant laser device used in inertial confined fusion (ICF) experimental research is the largest optical engineering ever built by humans. It requires thousands of large aperture optical components, especially for optical components with diagonal dimensions close to or exceeding 1 meter, which leads to the manufacturing is extremely difficult. Wavefront error, spectral property and surface defects are the key parameters of meter-size optical components. Precise measurement and precise control are required throughout the manufacturing process. In this talk, the research progress of the measurement techniques for large aperture optics will be presented. Their applications to different kinds of optics will also be introduced.

Topic: SS15: Quantitative phase imaging
Abstract No: 15468

Deep learning-enabled pixel super-resolution quantitative phase microscopy from single-shot intensity measurement

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Content

Quantitative phase imaging (QPI) is a promising technique in optical microscopy revealing the structure and optical properties of cells. Conventional QPI methods suffer from the trade-off between pixel resolution and field-of-view (FOV), and acquiring an intensity stack by scanning illumination angle or *z*-focus is generally time-consuming and requires a large number of intensity measurements. To overcome these limitations, we propose deep learning-based pixel super-resolved quantitative phase microscopy (DL-SRQPI) and achieves rapid wide-field high-resolution and high-throughput quantitative phase reconstruction from single-shot low-resolution intensity measurement. By training a neural network with sufficient pairs of low-resolution intensity and high-resolution phase data, the network is empowered with the capability to robustly reconstruct high-quality phase information from a single frame of aliased intensity image. As a graphics processing units (GPU)-accelerated computational method with minimal data requirement, DL-SRQPI is also well-suited for live-cell imaging and accomplishes high-throughput long-term dynamic phase reconstruction. The proposed method has been successfully implemented into the quantitative phase reconstruction of biological samples under off-the-shelf bright-field microscopes, overcoming pixel aliasing and achieving significant improvement in SBP of the imaging system. The generalization ability of DL-SRQPI is illustrated by the phase reconstruction of HeLa cells at different cases of defocus distances and illumination patterns. Given its capability of achieving pixel super-resolved quantitative phase imaging from single-shot intensity measurement over conventional bright-field microscope hardware, the proposed approach is expected to be widely adopted.

Keywords: quantitative phase imaging; phase retrieval; high-throughput microscopy; deep learning; super-resolution

Topic: SS15: Quantitative phase imaging
Abstract No: 15589

Computational phase imaging for label-free 3D microscopy

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Content

Abstract: Nowadays, fluorescence microscopy has made the leap from 2D to 3D or even 4D (xyz+t) imaging. On the other hand, Zernike phase contrast microscopy, which was awarded the Nobel Prize in Physics in 1953, has become the standard feature for modern biological microscopy, but is still limited to 2D imaging. Currently, life science research urgently needs a new "label-free 3D microscopy" mode that complements confocal/two-photon/super-resolution 3D fluorescence microscopy technology to meet the needs of rapid, high-resolution, long-term imaging of live cells in 3D. In this talk, we will present some of our research progress in "noninterferometic" intensity diffraction tomography, including: quantitative phase imaging and diffraction tomography based on transport of intensity and Fourier ptychography. Our results highlight a new era in which strict coherence and interferometry are no longer prerequisites for quantitative phase imaging and diffraction tomography, paving the way toward new generation label-free three-dimensional microscopy, with applications in all branches of biomedicine.

Keywords: phase imaging, label-free 3D microscopy, transport of intensity, Fourier ptychography

Topic: SS15: Quantitative phase imaging
Abstract No: 15647

High-quality dynamic phase imaging based on Fourier ptychographic microscopy

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Content

In order to overcome the limitations of traditional optical microscopes and simultaneously achieve high-throughput microscopy imaging and long-term dynamic quantitative phase imaging, emerging computational optical imaging technologies such as Fourier ptychographic microscopy (FPM) have been introduced. A large number of new theories and methods break through the limitations of optical imaging systems, and give revolutionary advantages that are difficult to obtain. In order to promote the application of high-throughput quantitative phase imaging technology in the fields of biomedicine and life sciences, we have carried out a series of research work on FPM. We first derived the phase transfer function of FPM, ensuring that FPM can accurately recover low-frequency phase information, thereby improving the accuracy of phase imaging. At the same time, we also studied the annular illumination scheme, which significantly improved the imaging speed of FPM and achieved single-frame phase imaging. This annular illumination strategy can also be transplanted to many other quantitative phase imaging techniques, such as transport of intensity equation (TIE) and differential phase contrast (DPC) imaging. In addition, during long-term observation of living cells, system instability often leads to variable aberrations and variable boundary conditions, which seriously affects the accuracy of phase recovery. To this end, we proposed an FPM algorithm with adaptive aberration correction capabilities and solved the boundary condition problem. Using this algorithm, we significantly improved the accuracy and stability of phase imaging during long-term dynamic measurements. This will further promote the applications of label-free dynamic phase imaging in fields of biomedicine and life sciences.

Keywords: Computational optical imaging; quantitative phase imaging; super-resolution microscopy; Fourier ptychographic microscopy

Topic: SS15: Quantitative phase imaging
Abstract No: 15679

Deep-learning Quantitative Phase Imaging for High Throughput Live-cell Imaging and Analysis

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Content

Renjie Zhou is an Associate Professor of the Department of Biomedical Engineering and Assistant Dean (Research) of Faculty of Engineering at CUHK, where he directs the Laser Metrology and Biomedicine Laboratory (LAMB). He received PhD in Electrical and Computer Engineering from the University of Illinois at Urbana-Champaign in 2014 and undertook postdoctoral training at MIT between 2014-2017. His research interest is in developing optical precision instruments for various research and industrial applications. He has published over 100 journal and conference papers and filed over 10 US/China patents with several licensed to industry. He has been involved in organizing > 20 international conferences as co-chairs/committee members, delivered >40 conference invited talks and seminars/colloquiums, and reviewed for >30 international journals. He is currently serving on the editorial boards of JOSA A, IEEE Photonics Technology Letters, and International Journal of Extreme Manufacturing. He is a Senior Member of Optica and SPIE. He received the Croucher Innovation Awards in 2019 from the Croucher Foundation and the Young Scientist Award at PIERS 2023 conference organized by the Electromagnetics Academy.

Topic: SS15: Quantitative phase imaging
Abstract No: 15681

Multi-harmonic structured illumination based optical diffraction tomography (MHSI-ODT)

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Content

Imaging speed and spatial resolution in optical diffraction tomography (ODT) are two key factors, while they are mutually exclusive in 3D refractive index imaging. This talk presents a multi-harmonic structured illumination based optical diffraction tomography (MHSI-ODT) to acquire 3D refractive index (RI) maps of transparent samples. MHSI-ODT utilizes a digital micromirror device (DMD) to generate structured illumination containing multiple harmonics. For each structured illumination orientation, four spherical spectral crowns are solved from five phase-shifted holograms, meaning that the acquisition of each spectral crown costs 1.25 raw images. Compared to conventional SI-ODT, which retrieves two spectral crowns from three phase-shifted raw images, MHSI-ODT enhances the imaging speed by 16.7% in 3D RI imaging. Meanwhile, MHSI-ODT exploits both the 1st order and the 2nd order harmonics, and therefore, it has a better intensity utilization of structured illumination. We demonstrated the performance of MHSI-ODT by rendering the 3D RI distributions of 5-μm polystyrene (PS) microspheres and biological samples.

Topic: SS16: Single-pixel imaging and optical encoding
Abstract No: 15464

Image-free feature tracking by Single-pixel Imaging Technologies

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Content

Single-pixel imaging is a novel computational imaging approach that reconstructs pictures from optical modulation, intensity measurement, and computation.

However, single-pixel imaging suffers from its low temporal and spatial resolution, especially when acquiring information with traditional post-processing method.

In this paper, based on single-pixel imaging method, we propose to utilize optical modulation and measurement to directly acquire scene information, such as object position and wanted features without the need of image reconstruction.

Operating at extremely low sampling rates and without image reconstruction, these methods enable the direct acquisition of the required information, thereby significantly enhancing the practical usability of single-pixel imaging technology.

Keywords: single-pixel imaging;Image-free; information acquisition

Topic: SS16: Single-pixel imaging and optical encoding
Abstract No: 15492

High-quality object reconstruction based on single-pixel imaging in highly dynamic scattering environments (invited)

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Content

Realizing high-quality object reconstruction in complex scattering environments is always a tremendous challenge, especially in highly dynamic scattering environments. Scaling factors in single-pixel measurements can be considered constant in a static environment. A highly dynamic scattering environment can result in randomly changed scaling factors in single-pixel measurements. Temporal correction is a powerful tool to eliminate the effect of randomly changed scaling factors on object reconstruction in single-pixel imaging. In this paper, we propose a high-quality object reconstruction method based on Hadamard single-pixel measurement in highly dynamic scattering environments. In the proposed method, the sequence of Hadamard patterns is randomly ordered, and then the disordered Hadamard patterns are applied to illuminate an object. Before detection, the object light passes through a dynamic and turbid water tank. In this case, randomly changed scaling factors can be obtained in single-pixel measurements based on the Hadamard method. A temporal correction method is applied to eliminate the randomly changed scaling factors in single-pixel measurements. Without temporal correction, no information about the object can be recovered in highly dynamic scattering environments. After the temporal correction, high-quality object reconstruction is realized in highly dynamic scattering environments. Experimental results are presented to demonstrate validity and feasibility of the proposed method.

Keywords: single-pixel imaging; Hadamard transform; Dynamic scattering environments

Topic: SS16: Single-pixel imaging and optical encoding
Abstract No: 15499

Optical pixel-to-plane encoding with neural network for ghost transmission through complex scattering media

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Content

Ghost transmission through multiple scattering and turbid media (e.g., turbid water, fog) remains an open question. Here, we propose high-fidelity ghost transmission through complex scattering media using random patterns as information carriers. Pixel values of an analog signal to be transmitted are sequentially encoded into random patterns by employing the untrained neural network (UNN). In optical experiments, the laser beam illuminates the designed random patterns and passes through complex scattering media. The total light intensities recorded by a single-pixel detector are used to retrieve the encoded analog signal. Experimental results demonstrate that the developed pixel-to-plane pattern encoding procedure can achieve high-quality ghost transmission through complex scattering media. The proposed method provides a solution for ghost transmission in complex environments by applying UNN for optical encoding.

Keywords: ghost transmission, complex environments, information carriers, untrained neural network, pixel-to-plane pattern encoding

Topic: SS16: Single-pixel imaging and optical encoding
Abstract No: 15501

Random Encoding with Modified Gerchberg-Saxton Algorithm for Accurate Ghost Transmission through Complex Scattering Media

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Content

High-fidelity information retrieval through complex scattering media has always been a challenge. To address this issue, we present a modified Gerchberg-Saxton (GS) algorithm that generates random amplitude-only patterns to serve as information carriers. The modified GS algorithm imposes a support constraint to a random pattern in the image plane, and scales the amplitude of its Fourier spectrum to control the sum of the pattern. Therefore, the random patterns generated by the modified GS algorithm are encoded with pixel values corresponding to the transmission data. The encoded patterns are sequentially displayed on a spatial light modulator and the modulated optical wave is finally recorded by a single-pixel detector. Optical experiments have been conducted to evaluate the proposed method under various conditions, such as dynamic turbid water and non-line-of-sight environments. It is verified that the proposed method can realize high-fidelity ghost transmission in complex scattering media.

Keywords: Optical encoding; optical analog-signal transmission; scattering media

Topic: SS16: Single-pixel imaging and optical encoding
Abstract No: 15506

Secured optical data transmission through dynamic scattering media using pixel-to-plane optical data encoding

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Content

In this paper, we report an approach to realizing optical data transmission through dynamic scattering media using pixel-to-plane data encoding strategy, and high-fidelity and high-security transmission can be effectively realized. A signal is considered as a sequence of separate pixels which are sequentially encoded. We generate a series of 2D patterns as information carriers to be used in the designed optical transmission channel. To suppress noise, a differential protocol is further designed and applied. In the designed optical system, numerous random keys are generated to guarantee the security. The absorptive filters are arbitrarily and flexibly used, and then ciphertext with high randomness can be obtained at the receiving end. Our experimental results illustrate validity of the method. Only when the keys are correct at the receiving end, the encoded data can be retrieved. It is expected that this approach can be useful to secure free-space optical data transmission through dynamic scattering media.

Keywords: Free-space optical communication; Encrypted transmission; Dynamic scattering media; Optical data encoding.

Topic: SS16: Single-pixel imaging and optical encoding
Abstract No: 15517

Image-free multi-object tracking based on multi-channel single-pixel imaging system

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Content

Multi-target tracking has garnered significant attention in recent years due to its potential in various fields such as academia, urban public security, military, and autonomous driving. Most methods of multi-target tracking rely on video sequences obtained through traditional imaging technology. However, the large volume of image data and the computational processing required present challenges in achieving real-time and long-term monitoring.

To address these limitations, this paper utilizes a novel computational imaging technology known as single pixel imaging, which can modulate the target scene before reconstructing the picture. Aiming at the task of multi-target tracking, we design a special modulation mode to directly acquire the information of multi-target positions and their identities from 1D data without reconstructing image. Additionally, a multi-channel system is used to enhance positioning accuracy and reduce the sampling rate. This innovative approach offers a distinct method for multi-target tracking and holds great potential for various applications.

Topic: SS16: Single-pixel imaging and optical encoding
Abstract No: 15611

An optical image encryption method based on Fourier single-pixel imaging and iterated phase retrieval algorithm

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Content

An optical image encryption method is proposed based on Fourier single-pixel imaging and iterated phase retrieval algorithm. First, a binary barcode image containing two groups of horizontal strips is randomly generated and processed with Fourier transform. The phase of the transformed result is obtained using the phase-truncated calculation and scrambled with the help of the sequence generated with logistic map. Second, the original image is initially encrypted using exclusive-OR between it and a chaotic matrix. Considering the encrypted image and phase information of the barcode image as the amplitude and phase constraint, two phase-only matrices are obtained using the phase retrieval algorithm in Fresnel domain and used as secret keys. Finally, the barcode image is encoded to a series of measurements using two-step phase-shifting Fourier single-pixel imaging. Also, these measurements are scrambled in the imaging process and considered as the ciphertext. Differing other methods, the original image is not directly imaged and encoded into the ciphertext. Even the ciphertext is obtained by a cracker, only the barcode image may be further discovered. Besides two phase-only matrices, parameters of logistic map are also used as secret keys. Therefore, the security level can be enhanced greatly. The simulated results verify the feasibility of the proposed method, and the work provides an effective alternative for the related research.

Keywords: Fourier single-pixel imaging; iterated phase retrieval algorithm

Topic: SS16: Single-pixel imaging and optical encoding
Abstract No: 15643

Research on Single Pixel Imaging Method for Moving Object

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Content

When single pixel imaging is used for imaging moving objects, severe motion blur often occurs in the solution image, which is one of the difficulties faced in the practical application of single pixel imaging. Two anti motion blur single pixel imaging schemes have been proposed for this purpose: the first scheme utilizes the system to obtain one-dimensional projection curves of moving objects in different directions, calculates the corrected Radon spectrum of the equivalent object in a stationary state based on the positional relationship between the one-dimensional projection curves, and finally reconstructs a clear image of the object, which can also synchronously output the motion trajectory of the object; The second scheme involves cyclic modulation and sampling of the target's position and image information by positioning and imaging modes, respectively. During the reconstruction process, the position of the target in each sampling period is calculated, and combined with the collected intensity information and imaging spatial modulation mode, the target is compensated for motion to reconstruct a clear image. Simulation and experimental studies were conducted on two schemes, and the results showed that the proposed method can effectively reduce motion blur and restore clear images of rapidly moving objects without prior knowledge.

Topic: SS16: Single-pixel imaging and optical encoding
Abstract No: 15660

High Speed Photoacoustic Microscopy based on Single Pixel Imaging Method

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Content

Photoacoustic imaging possesses the merits of both high optical contrast and large acoustic penetration. It is expected to play a more and more important role in both fundamental research and clinical applications, and has the potential to revolutionize the playground of tumor and cardiovascular disease management and treatment. In this talk, I will focus on how we improve the speed of photoacoustic microscopic imaging. I will start with conventional photoacoustic microscopy using point-by-point mechanical scanning. Then I will move on to fast optical scanning based on MEMS and polygon mirror devices. After that, I will introduce single pixel imaging method without the need of scanning. Combined with sparse sampling, the imaging speed can be improved by 20 times. We applied our technology and instrumentation to study tumor microenvironment and evolution of tumor, as well as to investigate the mechanism of neurovascular coupling in the brain. Our technology is valuable in terms of playing a fundamental role in basic science research and translational research.

Topic: SS17: Infrared thermography and structural health monitoring
Abstract No: 15487

Infrared colorimetric temperature measurement based on a two-band metalens

Zhendong LUO[*1] ; Peng Zhang[1] ; Huwang Hou[1] ; Yiming Li[1] ; Yang Zhao[1]

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Content

The response of traditional Infrared detectors can be affected not only by temperature but also by the emissivity of objects and optical transmittance of systems. In the real world, the emissivity of different objects varies greatly, which makes difficulties in dynamic detection under complex backgrounds. Colorimetric temperature measurement can reduce the error caused by emissivity of objects to a great extent, but at the same time lead to bulk optical systems or complex focal plane structures. Based on the characteristics of compact structure, light weight and customizability, a two-band metalens is designed to realize infrared colorimetric temperature measurement with the central wavelength of 9.5 microns and 12.5 microns, respectively. In the Finite-Difference Time-Domain simulation, the incident plane light of 8-14 microns is focused into two spots on the focal plane with a spot diameter of 30 microns and a spacing of 1 centimeter. Theoretically, the spectral focusing efficiency corresponding to the two focal spots is obtained and the formula of colorimetric temperature measurement is derived. Experimentally, infrared imaging with the two-band metalens is demonstrated and the colorimetric temperature measurement of different objects without presetting emissivity is realized. By this colorimetric temperature measurement method achieved with fabricated two-band metalens, the measurement errors caused by emissivity of objects is eliminated remarkably while keeping the optical system simple and compact. This provides a new opportunity for dynamic detection of compact infrared detectors in complex environments.

Keywords: Infrared imaging; Colorimetric temperature measurement; metalens;

Topic: SS17: Infrared thermography and structural health monitoring
Abstract No: 15512

Online Detection Method for Additive Manufacturing Printing Based on Near-Infrared Dual-wavelength Thermometry

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Content

Additive manufacturing (AM) is an important production trend. Meanwhile, the lack of an online defect detection technology is a key problem that limits the further development of AM. To realize effective online monitoring of defects, an online melt pool defect detection method and system based on near-infrared dual-wavelength thermometry is proposed in this study. Synchronous monitoring of the printing process was realized, and images of the temperature distribution and evolution of the melt pool with high resolution were obtained online. Focusing on the identification of temperature features by analyzing the evolutionary patterns of the melt pool temperature field, the online melt pool defect detection method has been developed, enabling the identification of surface porosity defects and high deviations in the production process. By leveraging the distinct characteristics of near-infrared dual-wavelength light, the system achieves remarkable sensitivity and resolution in capturing variations in deviation and defects, ensuring the timely detection and rectification of potential anomalies. Subsequently, an online measuring and verification experiment was designed to assess the height deviation of thin-walled structural parts. The results of our experiments demonstrate the effectiveness and reliability of the proposed method, showcasing its potential as a valuable tool for online quality control in industrial manufacturing processes.

Keywords: Additive Manufacturing; Near-infrared; Dual-wavelength Thermometry; Melt Pool Temperature; Defect Detection

Topic: SS17: Infrared thermography and structural health monitoring
Abstract No: 15639

A method for identifying precursors information on infrared radiation of instability and failure in wood

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Content

Anomalies in infrared radiation temperature (IRT) are usually accompanied via the sprouting and expansion of cracks. Precursor information of crack sprouting and extension is essential for predicting the condition as a material of structural fields. In order to investigate the precursor information of instability and failure of wood, the infrared radiation characteristics of wood during failure were analyzed by a three-point bending test. Based on the IRT probability distribution conforming to the Gaussian distribution, an indicator is defined in this paper: the peak probability density (PPD) of IRT. The changes in PPD were combined with the four stages of typical damage to determine the precursor information, and identified a precursor point on the PPD-time curve. The relations between IRT indicators and wood fracturing were also investigated to explain the anomalies in IRT indicators, the precursor point characterize the transition zone from the elastic to the plastic phase of deformation when the wood is under pressure. Besides, the samples before and after the precursor point were also compared by macroscopic (digital image correlation, DIC) and microscopic (scanning electron microscope, SEM), the results proved the validity of the precursor information. Comparison with other IRT indicators, the IRT indicator proposed in this paper has a higher sensitivity to IRT abnormalities in the failure process of wood structures.

Keywords: Infrared radiation temperature (IRT); Precursor information; Probability density; Chinese fir

Topic: SS17: Infrared thermography and structural health monitoring
Abstract No: 15653

Non-destructive Evaluation using Continuous Laser-Line Scanning Thermography with an Improved Data Processing Algorithm

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Content

Composite materials have been widely used in advanced engineering structures and high-end manufacturing industries due to their excellent physical properties. Non-destructive evaluation (NDE) is a valued discipline which plays an important role in assuring that these structures or components perform their function safely, stably and efficiently. As a new emerging NDE method, line scanning thermography is efficient for defect detection and location, especially in the detection of large specimens. In this work, a continuous laser-line scanning thermography(CLST) combined with an improved data processing algorithm is developed for high-accurate, high-efficient nondestructive evaluation of large structures, and experiments are conducted on samples with defects at different scanning speed to verify the stability and accuracy of the method. The results indicate that the CLST is robust for defect detection at different scanning speed, and high accurate measurement of defect can be obtained at circumstances of information redundancy or absence when the sampling frequency does not exactly match the scanning speed.The present approach is validated as a promising tool in continuous non-destructive evaluation of large structures in terms of accuracy and efficiency.

Keywords: Non-destructive evaluation; Continuous laser-line scanning thermography; Image reconstruction; Distortion correction.

Topic: SS18: X-ray optics and metrology
Abstract No: 15662

Requirements of the SHINE optics and consideration of their optical metrology

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Content

This talk aims to outline the essential requirements for the optics of the Shanghai HIgh repetitioN rate XFEL and Extreme light facility (SHINE) and to discuss fundamental considerations regarding optical metrology. SHINE is a new facility that generates intense X-ray Ultrafast femtosecond pulses for advanced scientific research. As the performance of the optics is critical to achieve high-quality X-ray flashes, it is crucial to understand the specific requirements and challenges associated with SHINE's optical system. It highlights the principal requirements of SHINE optics, such as high reflectivity, high stabilities, and ultra-smooth surface shape quality. Furthermore, it explores the importance of optical metrology techniques for ensuring the quality and reliability of the optical components. Various metrology methods, including LTP/NOM and interferometry, are discussed in the context of SHINE optics. By addressing the technical requirements and metrology considerations of SHINE optics, this talk is trying to provide insight thoughts for the ongoing development and optimization of the facility's optical system.

Keywords: Optical metrology; interferometry; X-ray mirrors; SHINE optics

Topic: SS18: X-ray optics and metrology
Abstract No: 15470

Surface Interferometric Measurement Method with Higher Accuracy for X-ray Optical Applications

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Content

The continuous development of X-ray optics has put forward new requirements for the ultra-precision optical manufacturing. Generally, the ultra-precision optical manufacturing requires the corresponding measurement capabilities. The surface shape of X-ray optical components typically includes the plane, cylinder, elliptical-cylinder and ellipsoid etc. Surface shape is one of the key parameters in X-ray optics, and the interferometric technique is a widely applied method for surface measurement. However, there are still technical challenges in surface interferometric measurement with higher accuracy for X-ray optical applications. In this presentation, a brief overview of the development status and trends of surface interferometric method is summarized. For X-ray optical applications, the flat absolute measurement method, cylindrical and elliptical cylindrical surface measurement with computer-generated holograms and stitching method are mainly presented. Meanwhile, some comparative experimental results are provided and discussed.

Keywords: Optical measurement; Surface Metrology; Interferometry; Absolute Measurement;

Topic: SS18: X-ray optics and metrology
Abstract No: 15472

Sub-aperture Stitching Interferometry with Dual Quaternion for X-ray mirrors

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Content

With the continuous development of the next-generation light sources represented by the synchrotron and free-electron laser light source beamlines, the quality requirements of surface for ultra-precision optical elements have significantly increased. The final surface quality of ultra-precision optical components depends on the surface measurement ability. At present, the sub-aperture stitching interferometry can effectively expand the measurement range of the interferometer, so as to obtain more abundant surface information, which is an effective surface measurement method for X-ray mirror. In this paper, the basic principle of stitching interferometry is briefly described, and a sub-aperture stitching algorithm based on dual quaternion (SSI-DQ) is proposed. We use the dual quaternary instead of the rotational matrix to express the position state of the sub-aperture in the space, and solve the spatial position difference of adjacent sub-apertures by combining the Lagrange multiplier method to realize the spatial position correction of sub-aperture. The experimental results obtained on a high quality elliptical cylindrical mirror with 100 m of radius of curvature show that the residual differences of 0.79 nm RMS between the surface errors were acquired with the SSI-DQ and LTP. On the other hand, SSI-DQ with wavelength tuned interferometer (WTI) to perform multi-dimensional stitching experiments on a 6.3-mm-thick, 6-inch thin parallel plate. The experimental results show that the measurement accuracy of this method can reach at least 0.5nm rms. To sum up, SSI-DQ has high stitching accuracy and can be applied to a variety of different measurements.

Keywords: Optical measurement; Surface Metrology; Sub-aperture Stitching Interferometry; X-Ray mirrors;

Topic: SS18: X-ray optics and metrology
Abstract No: 15474

X-ray optics development and metrology at Shanghai Synchrotron Radiation Facility

Lian Xue*[1] ; Zhongliang Li[1] ; Yumei He[1] ; Shangyu Si[1] ; Haipeng Zhang[1] ; Naxi Tian[1] ; Hongxin Luo[1]
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Content

Modern third-generation synchrotron radiation sources provide more collimated, brighter, and coherent X-ray beams for experimental techniques. X-ray optics are the bridge between the light sources and the experimental stations. Any defect (either from mirrors or crystals) will bottleneck preventing the exploitation of the full characteristics of the source. In addition to high-quality X-ray optics, mirror mounting, and handling of thermal deformation are also of critical importance. Advanced metrology to properly exploit all the new potential of these optics is needed. Shanghai Synchrotron Radiation Facility (SSRF) has metrology labs equipped with visible-light-based measuring instruments and X-ray test beamline for in-situ metrology. In this article, we will present the current state of the art of mirrors, crystals, and diagnostics at SSRF.

Keywords: X-ray optics; Metrology; Beamline

Topic: SS18: X-ray optics and metrology
Abstract No: 15486

Specular surface shape measurement with collimated phase measuring deflectometry

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Content

We present our innovative research and development efforts, resulting in a novel metrology solution for freeform optics based on on-axis deflectometry and fringe phase measurement. Our approach incorporates collimated camera rays with a telecentric imaging lens and collimated structured-light illumination using a Fourier lens. That is the reason we call this new deflectometry technique Collimated Phase Measuring Deflectometry (CPMD). This setup makes the fringe phases become only sensitive to the surface slopes and insensitive to the depth of the sample positioning. Thus, our technique achieves theoretical independence of slope calculation from sample depth, enhancing measurement accuracy and reliability.

In this talk, we provide a comprehensive exploration of CPMD. We detail the system configuration, its underlying principles, data acquisition, and data analysis. We demonstrate the robustness of CPMD by evaluating measurement repeatability, revealing exceptional performance. Several showcased measurement examples demonstrate the practical applicability of our CPMD setup, highlighting its potential in various industrial and scientific metrology applications. Finally, we discuss the merits and limitations of the proposed CPMD technique, revealing its prospects in practical metrology applications and potential future investigations.

Keywords: Phase measuring deflectometry; specular surface shape measurement; metrology; fringe analysis; mirror metrology

Topic: SS18: X-ray optics and metrology
Abstract No: 15504

Development and Characterization of Stress-free Laue Diffraction Crystal for X-ray Beam Splitting

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Content

To achieve the effective splitting of X-ray, perfect crystals with the space of lattice plane comparable to the X-ray wavelength can be used as splitter optical elements, which utilizes the diffraction effect of Laue crystal to accurately manipulate the X-ray beam. A stress-free thin crystal is crucial for high-quality X-ray splitting. The crystal's working area was thinned through acid corrosion. Additionally, the crystal's base cutting from the whole crystal was used for clamping during processing and experiment, which prevented the spread of stress to the working area of the crystal. The experiment of Laue diffraction was conducted at synchrotron radiation facility. In order to obtain the inherent rocking curve and consistent imaging field of view, a non-dispersive configuration was employed to match the energy bandwidth of the incident beam with the Laue diffraction crystal. Then diffraction splitting within the energy bandwidth of the Laue crystal was achieved by utilizing a collimator to reduce the divergence of the incident beam. The fine structure of the diffraction curve was measured experimentally, and the slope error of linear fitting between the high-angle and low-angle peaks was less than 0.4%, which satisfies the requirement of stress-free diffraction splitting. The design and characterization of this Laue diffraction crystal provides technical support for various applications, such as X-ray ghost imaging, X-ray multi-projection imaging, and beam line measurement at wavelength.

Keywords: Stress-free Crystal; Laue Diffraction; X-ray Beam Splitting

Topic: SS18: X-ray optics and metrology
Abstract No: 15577

The slope deflectometry system development for three dimensional profile measurement

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Content

Point-probe-based slope profiler such as LTP or NOM has been successfully used in high precision X-ray optics metrology. In this talk, we talk about our recent progress in developing slope deflectometry systems for three-dimensional profile measurement. The error in measurement induced by the limited spatial sampling is elaborated upon. To maintain accuracy while speeding measurement, a variable-sampling measurement scheme for distinct spatial frequency characteristics of the surface under test (SUT) is suggested.The system seeks to provide an alternative method for measuring freeform optical surfaces.

Keywords: slope profiler; x-ray optics; three-dimensional surface; noise

Topic: SS18: X-ray optics and metrology
Abstract No: 15587

Development of stitching interferometry and ion beam figuring methods for high precision X-ray mirrors

Qiushi Huang*[1] ; Qiaoyu Wu; Zhao Shi; Wenwen Zhang; Jun Yu; Yifan Zhu; Pengfeng Sheng; Zhong Zhang; Zhanshan Wang

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Content

Driven by the fast development of the new generation storage ring and free-electron laser facilities, X-ray mirrors with nanometer figure accuracy, complex shape and large size are widely demanded. These optics are being developed in Tongji University using stitching interferometry and ion beam figuring technique. Stitching interferometry is commonly used for the 2-D figure metrology of X-ray mirrors, while the accumulated angular error among neighboring subapertures and the systematic error within each subaperture are affecting the stitching accuracy. A method to correct the angular error using low-frequency profiles measured by other instruments is studied, called 'mixed stitching'. It directly obtains the stitching angles from the 1-D profile along one direction of the entire tested mirror which further correct the relative angles fitted from algorithm. The stitching accuracy can be both improved either by a commercial contact profiler or a high-precision slope measurement system and the minimum figure error of below 1 nm RMS can be achieved. The shape error of a single subaperture is further studied and reduced by calibration of the reference mirror and lateral resolution of the Fizeau interferometer. Based on these improvements, the measured figure accuracy of elliptical mirror using simple global stitching algorithm was improved to 1.5 nm RMS. To correct the surface error of large X-ray mirrors using ion beam figuring, both a standard 3-axis IBF process and a two-dimensional figuring method using one-dimensional motion system and multiple removal functions generated by mask was developed. The effect of noble ions sputtering on high frequency surface morphology of silicon was also studied to maintain the ultrasmall surface roughness of the mirror. Flat mirrors with maximum length of 500mm and figure height error of 1nm RMS were manufactured. Elliptical mirror with 1~2nm accuracy at the center area was manufactured which produced 207nm focus spot at 10keV. Some of the fabricated mirrors have been applied in the synchrotron radiation facility.

Topic: SS18: X-ray optics and metrology
Abstract No: 15625

Detecting and Characterizing Spatter Particles on Additively Manufactured Surfaces in 3D Using X-Ray Computed Tomography and Deep Learning

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Content

Metal additive manufacturing (AM) is a technology that can create geometrically complex engineering components by depositing material layer by layer. Because of its ability to create complex geometries, metal AM is receiving growing industrial attention for the fabrication of high-performance components required by the aerospace, oil and gas, marine, and space industries. However, as-printed AM components have much poorer surface quality compared to traditionally machined components, thereby compromising the quality of the final product. One primary defect is spatter particles, which may present stress concentrations at the surface of a component and lead to mechanical failure, or may be dislodged from the surface in fluid-flow applications. These 3D spatter particles have the potential to disperse across both external and internal surfaces, the latter are impossible to measure non-destructively using tactile or optical methods. In this work, we use X-ray computed tomography (XCT) and advanced 3D deep learning algorithms to intelligently detect and characterize 3D spatter particle defects for metal AM, where XCT allows both the internal and external surfaces of metal AM components to be measured. Our initial experimental results show that we can segment particles in 3D with an accuracy of approximately 88%.

Keywords: Spatter Particles; Metal Additive Manufacturing; X-ray Computed Tomography; 3D Deep Learning; Non-Destructive Inspection

Topic: SS18: X-ray optics and metrology
Abstract No: 15642

Developments of stitching interferometry techniques for the SHINE long X-ray mirrors surface shape measurement

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Content

For the SHINE long X-ray mirrors surface shape measurement, we have developed relevant sub-apertures absolute calibration and stitching interferometry techniques. In addition to the three-flat calibration, we proposed the transverse shear multi-matrix and the multiple measurements averaging method to eliminate Fizeau reference mirror errors. With the absolute sub-aperture surface shape, all sub-apertures can be stitched together into a full absolute mirror surface shape by stitching procedure. We compared and evaluated various stitching algorithms, then combined absolute metrology with stitching algorithms into a software platform. Measurement experiments show that the simple repeatability of sub-apertures measurements can reach λ/30000 rms, the residual surface repeatability is ~λ/6000 nm rms in 10-averaged 2D maps. We performed interferometric measurements on the JTEC meter-scale X-ray flat mirrors and obtained preliminary measure results: the centerline height error is 0.23nm rms and 1.29nm PV in 700×30 mm clear aperture. Future work is to calibrate accurately the Fizeau interferometer reference mirror and obtain absolute sub-apertures to efficiently optimize stitching interferometry of long X-ray mirrors.

Keywords: Optical metrology; Fizeau interferometry; Stitching interferometry; X-ray mirrors

Topic: SS18: X-ray optics and metrology
Abstract No: 15661

Sub-10 nm focusing of hard X-ray free-electron laser for reaching 10^22 W/cm^2 intensity

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Content

We have developed a sub-10 nm focusing system to achieve an ultraintense X-ray laser field with 10^{22} W/cm^2 intensity at SACLA. For the sub-10 nm focusing optics, we adopted an advanced Kirkpatricl–Baez (AKB) mirror system based on Wolter-type III geometry. One of the remarkable challenges was fabricating steeply curved mirrors with radii of curvature of ~3 m with a shape accuracy of 1 nm. We implemented an X-ray wavefront correction scheme using a single-grating interferometer and a differential deposition technique. The horizontal mirror pair was corrected twice and the vertical pair once, resulting in the wavefront error of λ/15 rms that satisfies Maréchal's criterion. Focus characterization was performed by single-grating interferometry and ptychography. Both methods consistently indicated a focusing spot size of 7 × 7 nm^2. Employing an ultra-intense XFEL pulses, we have preliminarily observed anomalous emission spectra from highly ionized solid-density atoms

Topic: SS18: X-ray optics and metrology
Abstract No: 15678

X-ray optical technology at High Energy Photon Source (HEPS)

Fugui Yang*[1] [1] ; Ming Li[1] [1] ; Weifan Sheng[1] [1]

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Content

HEPS, the 4th generation synchrotron radiation facility, is under construction in Beijing. The designed electron energy is 6GeV and the emittance is lower than 60pm·rad. The high-quality X-ray near diffraction limit brings unprecedented challenges to optical technology. This talk will present the progress of construction of HEPS briefly including accelerator, beamline and so on. It will be emphasized that the R&D status of X-ray optical technology at HEPS, such as optical metrology, fabrication, manipulation and so on.

Topic: SS19: Optical Engineering in Industry
Abstract No: 15480

All-in-one Microscope for 3D Inspection and Testing

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[1]R&D/ ImageX/d'Optron/ China (中国)

Content

Microscopes are ubiquitous instruments with applications in a wide range of industries from Semi-con to Biomedical. With its over 150 years of evolution, microscopes have developed into go to instruments for high magnification imaging and measurement. With such a superior optics instrument, numerous adaptations to the microscope have been introduced in current years. Most of these have targeted the bio-imaging arena with additions such as fluorescent imaging and laser confocal depth slicing amongst others. However, these are primarily targeting the bioimaging market. For industrial 3D imaging, very few adaptations have been introduced. In this presentation, we will demonstrate two sets of additions to standard microscopes which will provide different 3D modalities for quantitative depth imaging. The first system is for geometric optics-based 3D imaging systems. This includes the stereovision, fringe profilometry, photometric stereo and AI for inspection modules. MATLAB® codes are provided to drive these modules and process the data. This makes it easy for users to modify, fine-tune and edit the system for their specific applications. It thus provides a single testbed for selecting the appropriate module for 3D inspection and testing. The second system utilizes physical optics-based 3D measurement systems based on the Transport of Intensity Equations, polarimetry and Fourier ptychographic microscopy (FPM). These work primarily on specular or transparent objects found in microsystem and micro and diffractive optics-based components. Demo of these systems would also be shown at our exhibit during the conference.

Topic: SS19: Optical Engineering in Industry
Abstract No: 15520

An introduction of resin SRG wave guides in AR glasses

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Content

Firstly, this paper introduces the advantages and disadvantages of resin waveguides compared with glass waveguides. Then this paper introduces the difficulties in the manufacture of resin waveguides from the different manufacturing processes of resin material molding and modification, nano-imprinting and packaging. Finally, this paper introduces the different applications of resin waveguides in AR glasses.

Keywords: Resin SRG wave guides Nano-imprinting AR glasses

Topic: SS19: Optical Engineering in Industry
Abstract No: 15600

A Calibration Method for LED Point Light Sources in Near-Field Photometric Stereo

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Content

In near-field photometric stereo vision, the accurate calibration of the light source position directly affects the accuracy of the reconstruction results. Traditional calibration techniques rely on a highly reflective sphere and exploit the specular reflection properties at highlight points for determining light source positions. The calibration precision is influenced by the accuracy of extracting sphere edges and highlight points. Uneven surface illumination on the sphere, caused by a single point light source, introduces non-uniformity, prompting a trade-off during camera exposure between maintaining clear edge contours and minimizing highlight point size. To address this, we designed a new calibration target to overcome the inherent compromise between clear contours and minimal highlight points in camera exposure. This method resolves challenges associated with edge extraction under low-exposure conditions. The experiment demonstrates that the method improves the accuracy of light source position calibration, presenting a novel avenue for advancing research and application in the realm of near-field photometric stereo vision.

Keywords: Near-field photometric stereo; Calibration of LED light sources

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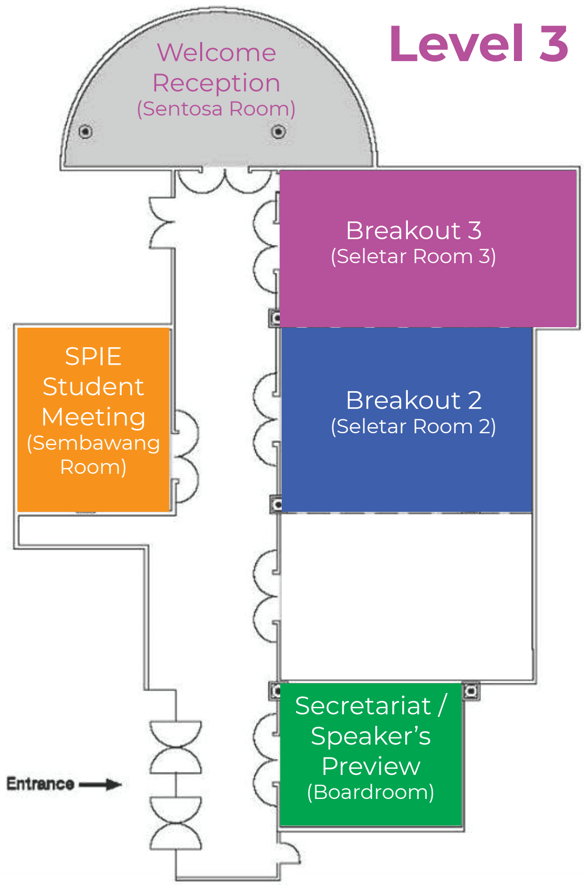

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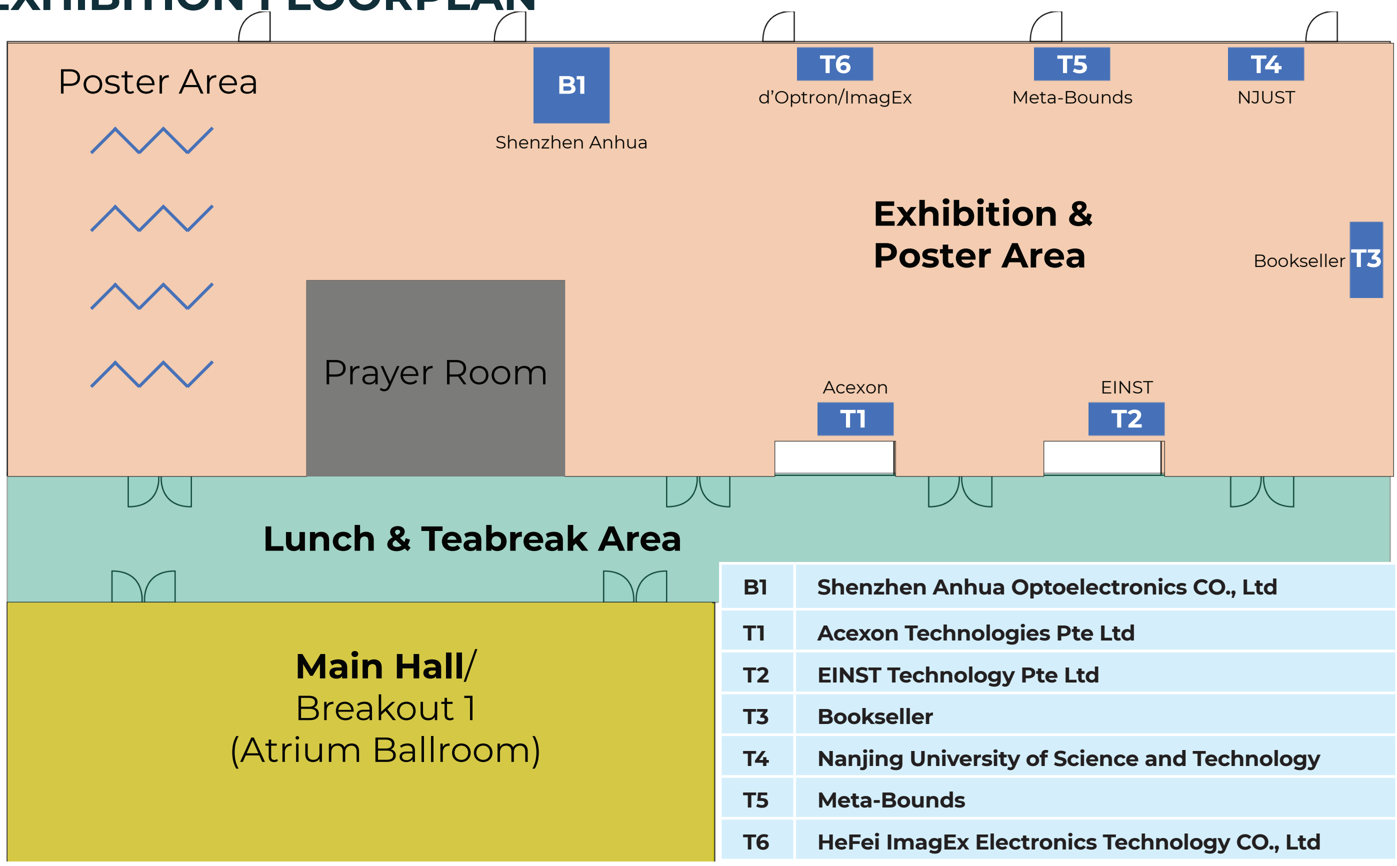

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