Digital Holography and Three Dimensional Imaging (DH)

9 May - 11 May 2011, University of Tokyo, Komaba Research Campus, Tokyo, Japan

DH – The topical meeting on Digital Holography and Three-Dimensional Imaging provides a forum for disseminating the

Thank you to everyone who made the trip to Tokyo and participated in DH 2011! The meeting was a great success and we are already looking forward to DH 2012 to be held in Miami, Florida from 29 April - 2 May. Please mark your calendars now!

A special thank you to our General Chairs, George Barbastathis and Toyohiko Yatagai, as well as our Local Host Committee Chair, Tsutomu Shimura, for all of their hard work and coordination.

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The topical meeting on Digital Holography and Three-Dimensional Imaging provides a forum for disseminating the fundamentals and applications of holographic and digital methods in optical science and technology, including holographic interferometry for deformation or contour measurement, new technologies for phase unwrapping,

3-D optical remote sensing, 3-D holographic microscopy, 3-D optical image processing, 3-D display, and digital holography for life science or nanophotonics applications.

Papers are being considered in the following topic categories:

- Digital Holography Theory and Systems
- Diffractive Optics
- Optical Data Storage
- Phase Unwrapping and Phase Retrieval
- Computer Generated Holograms
- Spatial Light Modulators for Holography
- Incoherent Digital Holography
- Holographic Optical Elements
- 2-D and 3-D Pattern Recognition
- Optical Correlators
- Three-Dimensional Imaging and Processing
- Three-Dimensional Display
- Stereo-Matching and Stereoscopic Cameras
- 2-D-3-D Content Conversion
- Shape and Deformation Measurement
- Polarization Analysis
- Holographic Imaging and Microscopy
- Holographic Nanofabrication Methods
- Holographic Optical Micro-Manipulation

A number of distinguished invited presentations have been invited to present at the meeting.

The 2010 meeting featured nearly 100 presentations, with speakers representing 20 countries. In addition, nearly 35% of the contributed presentations were submitted by students.

General Chairs:

- George Barbastathis, *MIT, USA*
- Toyohiko Yatagai, *Utsunomiya Univ., Japan*

Sponsor:

Cooperating Societies:

Digital Holography and Three Dimensional Imaging (DH)

9 May - 11 May 2011, University of Tokyo, Komaba Research Campus, Tokyo, Japan

Program

Digital Holography and Three Dimensional Imaging (DH): OSA Topic Meeting is designed to provide a forum for disseminating the fundamentals and applications of holographic and digital methods in optical science and technology, including holographic interferometry for deformation or contour measurement, new technologies for phase unwrapping, 3-D optical remote sensing, 3-D holographic microscopy, 3-D optical image processing, 3-D display, and digital holography for life science or nanophotonics applications.

The program for Digital Holography and Three Dimensional Imaging (DH) will be held Monday, May 9 through Wednesday, May 11, 2011.

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- Holographic Nanofabrication Methods
- Holographic Optical Micro-Manipulation

A number of distinguished **invited speakers** have been invited to present at the meeting. In addition, the organizers have planned a number of **special events** to make your meeting experience more enjoyable!

Special Events

Welcome Reception
Poster Sessions
Post Deadline Sessions

Digital Holography and Three Dimensional Imaging (DH)

9 May - 11 May 2011, University of Tokyo, Komaba Research Campus, Tokyo, Japan

Exhibit: *May 9-11, 2011 at The University of Tokyo, Komaba Research Campus, Tokyo, Japan*

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Tokyo, Japan is an exciting city of over 35 million inhabitants. It has many interesting tourist attractions including the Imperial Palace, the Tokyo National Museum and the quarter kilometer high Tokyo Tower. Tourists can visit Japan's parliament (the Diet) or enjoy a visit to Tokyo Disneyland.

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If you are already an exhibitor and you have questions about shipping, ordering furnishings or services and/or have any other logistically related questions, please call +1 202-416-1972 or topicalexhibits@osa.org.

Digital Holography and Three Dimensional Imaging (DH)
2011

9-11 May, 2011

University of Tokyo, Komaba Research Campus
Tokyo, Japan

Conference Program

Digital Holography and Three-Dimensional Imaging (DH)
9-11 May, 2011
Tokyo, Japan

Welcome to the 5th Digital Holography and Three-Dimensional Imaging (DH) Topical Meeting in Tokyo, Japan. The DH Topical Meeting is the world's premier forum for disseminating the science and technology geared towards 3-D information processing. Since the meeting's inception in 2007, it has steadily and healthily grown to 130 presentations this year.

The three-day program includes a plenary speaker, 3 tutorials, 17 invited speakers, 109 contributed oral presentations, and 85 poster presentations. At this meeting, expect to hear about the latest research on 3-D imaging, digital holographic microscopy, digital/electronic holography, 3-D displays and systems, integral photography and imaging, and holographic interferometry/modulators/filters/materials and much more.

We are thankful for the support from the DH community after the 11 March, 2011 earthquake and tsunami. Our thoughts go out to all who were affected by this disaster.

We are so happy that despite the recent events we are able to move forward and hold this year's meeting as planned.

We look forward to meeting you in Tokyo, Japan.

Sincerely,

Toyohiko Yatagai
Utsunomiya Univ., Japan
General Chair

George Barbastathis
MIT, USA
General Chair

2011 Digital Holography and Three-Dimensional Imaging Program Committee

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George Barbastathis, *Massachusetts Inst. of Technology, USA*
Toyohiko Yatagai, *Ctr. for Optical Science and Education (CORE), Utsunomiya Univ., Japan*

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Local Coordinator

Hiroshi Yoshikawa, *Nihon Univ., Japan*

Time	Monday, 9 May DH	Tuesday, 10 May DH	Wednesday, 11 May DH
8:00	**Registration 08:00-18:00**	**Registration 08:00-18:00**	**Registration 08:30-17:00**
8:30			
9:00	**Opening Remarks** (starts at 09:15)	**3-D Display Systems II**	**Entrepreneurship in Optics**
9:30	**Advances in Digital Holography I**		
10:00	**Coffee Break 10:15-10:45** *(Covention Hall Foyer)*		
10:30	**Advances in Digital Holography I—Continued (starts at 10:45)**	**Coffee Break 10:30-11:00** *(Covention Hall Foyer)*	**Coffee Break 10:30-11:00** *(Covention Hall Foyer)*
11:00		**Novel Approaches in Digital Holography I**	**Digital Holography in Metrology and Manupilation**
11:30			
12:00			
12:30	**Lunch Break** 12:30-13:30 (*on your own)*	**Lunch Break** 12:30-13:15 (*on your own)*	**Lunch Break** 12:30-13:15 (*on your own)*
13:00			
13:30	**Advances in Digital Holography II**	**Poster Session I** (13:15-14:30)	**Poster Session II** (13:15-14:30)
14:00			
14:30			
15:00		**Novel Approaches to Digital Holography II** (ends at 16.15)	**3-D Imaging and Microscopy** (ends at 16.15)
15:30	**Coffee Break 15:30-16:00** *(Covention Hall Foyer)*		
16:00	**3-D Display Systems I** (ends at 18.15)		
16:30		**Coffee Break 16:15-16:45** *(Covention Hall Foyer)*	**Coffee Break 16:15-16:45** *(Covention Hall Foyer)*
17:00		**Tutorial Session**	**Advanced Imaging and Tomography** (16:45-18:15)
17:30			
18:00			
18:30	**Happy Hour**	**Conference Reception**	**PDP Session and Closing Remarks**
19:00			
19:30			**DH Editors Dinner** *(offsite)*
20:00			
20:30			

2011 Digital Holography and Three Dimensional Imaging Plenary Speaker

Optical Scanning Holography: Origin, Modern Capabilities and Beyond, Ting-Chung Poon;
Virginia Tech, USA. **[Plenary]**
Monday, 9 May, 09:30-10:45, *Convention Hall (An-202)*

Ting-Chung Poon is Professor of *Electrical and Computer Engineering* at *Virginia Tech*. His current research interests include acousto-optics, 3-D image processing, and optical scanning holography. Dr. Poon is the author of the monograph *Optical Scanning Holography with MATLAB* (Springer, 2007), and is the co-author of the textbooks *Engineering Optics with MATLAB* (World Scientific 2006), *Contemporary Optical Image Processing with MATLAB* (Elsevier 2001), and *Principles of Applied Optics* (McGraw-Hill 1991). He is also Editor of the book *Digital Holography and Three-Dimensional Display* (Springer 2006) and has served as a panelist for the National Institutes of Health and the National Science Foundation, and as Guest Editor of, among other journals, ***International Journal of Optoelectronics***, ***Optical Engineering*** and ***Chinese Optics Letters***. Dr. Poon currently serves as Division Editor for ***Applied Optics***. He is the founding Chair of the OSA topical meeting *Digital Holography and 3-D Imaging*. Dr. Poon has been a member of the Board of Editors of the Optical Society of America (OSA) and is currently on the Editorial Board of ***Optics and Laser Technology***, the ***Journal of Holography and Speckle***, and the journal ***3D Research***. Dr. Poon is a fellow of the OSA and the Society of Photo-Optical Instrumentation Engineers (SPIE).

2011 Digital Holography and Three Dimensional Imaging Tutorial Speakers

Compressive Holography, David J. Brady; *Duke Univ., USA.* **(Tutorial)**
Tuesday, 10 May, 16:45 - 17:30, *Convention Hall (An-202)*

David J. Brady is the Michael J. Fitzpatrick Endowed Professor of Photonics at Duke University, where he leads the Duke Imaging and Spectroscopy Program. Brady is the author of *Optical Imaging and Spectroscopy* (Wiley-OSA 2009) and has developed numerous computational imaging systems. After completing Ph.D. studies focusing on volume holographic recording for interconnections and data storage, Brady worked on the use of holograms to control ultrafast systems while on the faculty of the University of Illinois. He stopped working in holography in 1996 and shifted his focus to integrated sensing and processing for incoherent imaging systems. After moving to Duke in 2001 as the founding director of the Fitzpatrick Institute for Photonics, Brady developed compressive sampling strategies for various projection tomography and spectral imaging systems. He returned to holographic studies in 2009 when he applied compressive sampling to digital holography.

Coherence Holography: A Tutorial Review, Mitsuo Takeda; *Univ. of Electro-Communications, Japan*. (Tutorial)
Tuesday, 10 May, 17:30 - 18:15, *Convention Hall (An-202)*

Mitsuo Takeda is Professor of Engineering Science Department at the University of Electro-Communications (UEC), Tokyo, Japan. He received the BE degree in Electrical Engineering from UEC in 1969, and the MS and Ph.D. degrees in Applied Physics from the University of Tokyo, respectively, in 1971 and 1974. After working for Canon Inc., he joined the faculty of UEC in 1977. During 1985 he was a visiting scholar of Prof. Joseph W. Goodman's Group at Stanford University. He has been on the Board of Directors for both the Japan Society of Applied Physics from 1993-1995 and the Optical Society of Japan from 1996-1997. He was also on the Board of Directors of SPIE in 2003 and from 2007-2009. His service to the technical community also includes his role as President of the Optical Society of Japan from 2010-2012.

Three Dimensional Sensing, Visualization, and Display by Integral Imaging Bahram Javidi[1], Manuel Martinez-Corral[1]**; *[1]ECE, Univ. of Connecticut, USA.* (Tutorial)**
Tuesday, 10 May, 18:15 - 19:00, *Convention Hall (An-202)*

Bahram Javidi is Board of Trustees Distinguished Professor at University of Connecticut. He has been named Fellow of eight scientific societies, including IEEE, OSA, EOS, SPIE, and IoP. He received the Fellow award by Guggenheim Foundation (2008), and 2008 IEEE Fink Prize Paper Award chosen among all (over 150) IEEE Transactions and Journals. In 2010, he was the recipient of The George Washington University's Distinguished Alumni Scholar Award, University's highest honor for its alumni in all disciplines. In 2007, The Alexander von Humboldt Foundation awarded Dr. Javidi the Humboldt Prize for outstanding US scientists, Germany's highest research award for senior U.S. scientists and scholars in all disciplines. He received the Technology Achievement Award from The International Society for Optical Engineering (SPIE) in 2008. In 2005, he received the Dennis Gabor Award in Diffractive Wave Technologies from SPIE. He was named and NSF Presidential Young Investigator early in his career. Laboratories in 1997, where his primary research interests were in fiber optic communications. He returned to Cornell University in 2002, and became an Associate Professor in 2007. His current research areas are biomedical imaging, fiber optics, and optical communications. He has published more than 140 journal and conference papers, including 7 book chapters and 5 invited reviews, and has 24 patents granted or pending. He has won the Tau Beta Pi and two other teaching awards from Cornell Engineering College since 2004.

Opening Remarks
Monday, May 9, 2011
09:15–09:30

DMA • Advances in Digital Holography I
Monday, May 9, 2011
09:30–11:30
George Barbastathis; MIT, USA, Presider

DMA1 • 09:30 Keynote
Optical Scanning Holography: Origin, Modern Capabilities and Beyond, Ting-Chung Poon[1]; [1]*Virginia Tech, USA.* I review the original idea of optical scanning holography, discuss its modern capabilities and finally mention some of the important applications that are worth pursuing in the future.

Coffee and Tea Break, *Convention Hall Foyer*
10:15-10:45

DMA • Advances in Digital Holography I—Continued
10:45–12:30
George Barbastathis; MIT, USA, Presider

DMA2 • 10:45 Invited
Nanophotonics for Information Systems, Yehaiahu Fainman[1]; [1]*Univ. of San Diego, USA.* This paper explores the role of nanotechnology with focus on nanophotonics in dielectric, metal, and semiconductor inhomogeneous composition materials, devices and subsystems for optical communications, information and signal processing, and sensing.

DMA3 • 11:15 Invited
Digital Holography for Coherent Imaging for Multi-Aperture Laser Radar, Joseph W. Haus[1], Nicholas J. MIller[1], Paul McManamon[1], David Shemano[1]; [1]*Electro-Optics Program, Univ. of Dayton, USA.* Active remote sensing challenges using multi-aperture imaging experiments are described. The image resolution is limited by the accuracy in phasing all sub-apertures together. Efforts to overcome technical hurdles in achieving high resolution imagery are reported.

DMA4 • 11:45
Sub-Aperture Techniques Applied to Phase-Error Correction in Digital Holography, Abbie E. Tippie[1], James R. Fienup[1]; [1]*Inst. of Optics, Univ. of Rochester, USA.* We correct for phase errors in a synthetic aperture digital holography experiment using sub-apertures. Relative image translations from sub-apertures are used to estimate 7th order polynomial phases and reconstruct images with improved resolution.

DMA5 • 12:00
Imaging Through Turbidity by Phase-Conjugate Scanning Microscope Using Second-Harmonic Beacon Nanoparticles, Chia-Lung Hsieh[1,2], Ye Pu[1], Rachel Grange[1], Grégoire Laporte[1], Demetri Psaltis[1]; [1]*School of Engineering, EPFL, Switzerland;* [2]*Electrical Engineering, Caltech, USA.* We demonstrate a novel technique to image through a diffuser by scanning the phase-conjugate second-harmonic field emitted from a nanoparticle.

DMA6 • 12:15
Compressive Holographic Inversion of Particle Scattering, Lei Tian[1], Justin W. Lee[1], George Barbastathis[1,2]; [1]*MIT, USA;* [2]*Singapore-MIT Alliance for Res. and Technology, Singapore.* Compressive sensing is applied to solve the holographic inverse source problem in the case of particle scattering. Both numerical simulations and experiments show good inversion results when the proposed method is applied.

12:30-13:30 Lunch Break, *Own your own*

DMB • Advances in Digital Holography II
Monday, May 9, 2011
13:30–15:30
Mitsuo Takeda; UEC, Japan, Presider

DMB1 • 13:30 Invited
Holography for Nano Metrology: A Tool in Microfluidic and for Lab-on-a-Chip Analysis, Pietro Ferraro[1]; *[1]CNR INO, Italy.* Digital Holography is a powerful tool for investigating and studying processes in microfluidic and lab-on-a-chip platforms. DH allows to perform quantitative phase-contrast, tracking and trapping of microbjects. Latest achievements will be presented.

DMB2 • 14:00 Invited
Lensfree Holographic Microscopy for Global Health Applications, Aydogan Ozcan[1]; *[1]Electrical Engineering, UCLA, USA.* We review our recent progress on lensfree holographic on-chip microscopy techniques that are aimed at global health applications including imaging of bodily fluids toward diagnosis of infectious diseases such as malaria and HIV.

DMB3 • 14:30
Phase-Only Hologram Generation from Multiple Defocused Images of Three-Dimensional Object, Ni Chen[1], Jiwoon Yeom[1], Keehoon Hong[1], Jisoo Hong[1], Jae-Hyun Jung[1], Jae-Hyeung Park[2], Byoungho Lee[1]; *[1]School of Electrical Engineering, Seoul Natl. Univ., Republic of Korea; [2]School of Electrical and Computer Engineering, Chungbuk Natl. Univ., Republic of Korea.* A phase-only hologram generation method of 3D objects is proposed. The 3D object is recorded into a series of defocused images. The phase-only hologram is generated from these images with iterative method.

DMB4 • 14:45
Three-Dimensional Deconvolution of Complex Fields, Yann Cotte[1], Isabelle Bergoend[1], Cristian Arfire[1], Shan shan Kou[1], Christian D. Depeursinge[1]; *[1]EPFL, Switzerland.* We present a technique for 3-D image processing of complex fields acquired by digital holographic microscopy. It consists in inverting the coherent imaging by filtering the complex spectrum with a pseudo three-dimensional coherent transfer function.

DMB5 • 15:00
Fresnel-Bluestein Transform for Numerical Reconstruction of Digitally Recorded Holograms, Jorge Garcia-Sucerquia[1], John F. Restrepo[1]; *[1]Univ. Nacional de Colombia Sede Medellin, Colombia.* The Fresnel-Bluestein (FB) transform is presented for numerical reconstruction of digitally recorded holograms. FB allows for changing the magnification of the reconstructed holograms independent of distances, wavelength and number of pixels.

DMB6 • 15:15
Fast Calculation Method for Computer Generated Cylindrical Holography, Jackin Boaz Jessie[1], Yamaguchi Takeshi[2], Yoshikawa Hiroshi[2], Toyohiko Yatagai[1]; *[1]Center for Optical Res. and Education, Utsunomiya Univ., Japan; [2]Electronics and Computer Science, Nihon Univ., Japan.* A fast calculation method for computer generation of cylindrical holograms using wave propagation in spectral domain is proposed. The generated cylindrical hologram was successfully tested for simulated and optical reconstructions.

Coffee and Tea Break, *Convention Hall Foyer*
15:30-16:00

DMC • 3-D Display Systems I
Monday, May 9, 2011
16:00–18:15
Byoungho Lee; Seoul Natl. Univ., Korea, Presider

DMC1 • 16:00 Invited
Future Holographic 3-D Television, Thomas Naughton[1]; [1]*Univ. Oulu, Finland.* Abstract not available.

DMC2 • 16:30 Invited
Technologies and Implementation Issues of Stereoscopic 3-DTV Broadcasting System, Jinwoong Kim[1], Seyoon Jeong[1], Jin Soo Choi[1], KyungAe Moon[1]; [1]*ETRI, Republic of Korea.* We review technologies and implementation issues of stereoscopic 3DTV broadcasting system in terms of capture, coding, display and viewing human factor. We do present analysis and experiment results of backward-compatibility and efficient video coding methods.

DMC3 • 17:00
Digital Holographic 3-DTV: Problems and Solutions, Thomas Kreis[1]; [1]*BIAS - Bremer Inst. für Angewandte Strahltechnik, Germany.* Holography promises 3DTV without accommodation conflict, but is hampered by the necessary high space-bandwidth product with consequences on capturing and display systems and computational effort. First approaches solving these problems are presented.

DMC4 • 17:15
Grayscale Image Reconstruction by Horizontally Scanning Holographic Display, Masahito Yokouchi[1], Yasuhiro Takaki[1]; [1]*Tokyo Univ. of Agriculture and Technology, Japan.* The grayscale image reconstruction by the horizontally scanning holographic display is improved. Several sets of elementary holograms are displayed with different illumination laser powers in a time-multiplexing manner. Four methods are compared.

DMC5 • 17:30
Bi-Sided Volumetric Display System Utilizing the Reflective and Transmissive Fields of Integral Imaging, Jisoo Hong[1], Sung-Wook Min[2], Byoungho Lee[1]; [1]*School of Electrical Engineering, Seoul National Univ., Republic of Korea;* [2]*Dept. of Information Display, Kyung Hee Univ., Republic of Korea.* We propose a novel system that utilizes the reflective and transmissive fields of the projection-type integral imaging. With the proposed system, bi-sided volumetric display is implementable for observation of a group of people.

DMC6 • 17:45 Invited
Integral 3-D TV Using the Pixel-Offset Method with Four 33-Megapixel Image Sensors, Jun Arai[1]; [1]*NHK, Japan Broadcasting Corporation, Japan.* We have developed integral 3-D television image capture equipment using four 33-megapixel image sensors. By capturing elemental images that exceed the Nyquist frequency of a 33-megapixel image sensor, we could suppress aliasing and improve resolution.

Happy Hour
18:30-19:30

DTuA • 3-D Display Systems II
Tuesday, May 10, 2011
Hiroshi Yoshikawa; Nihon Univ., Japan, Presider
09:00–10:30

DTuA1 • 09:00 Invited
fVisiOn: Glasses-free Tabletop 3-D Display-Its Design Concept and Prototype , Shunsuke Yoshida[1]; *[1]NICT, Japan.* fVisiOn is a novel, glasses-free tabletop 3-D display designed for tabletop interaction scenarios. It floats virtual 3-D objects on a flat tabletop surface and provides a natural mixed-reality environment for multiple people around the table.

DTuA2 • 09:30 Invited
Multiple Projector Displays, Chao-Hsu Tsai[1]; *[1] ITRI, China.* Abstract not available.

DTuA3 • 10:00
Full-Color Wide Viewing-Zone-Angle Electronic Holography System, Takanori Senoh[1], Tomoyuki Mishina[1], Kenji Yamamoto[1], RYutaro Oi[1], Yasuyuki Ichihashi[1], Taiichiro Kurita[1]; *[1]Universal Media Res. Ctr., Natl. Inst. of Information and Communications Technology, Japan.* We developed a no-color-breaking, electronic holography system with image size of 4 cm, viewing-zone-angle of 5.6/11.2/16.8 degrees, at frame rates of 60/30/20 Hz, respectively.

DTuA4 • 10:15
Real-Time Video Holographic System Based on Range Camera, Sub-Lines and Integrated Fresnel Lines, Wai Ming Tsang[1], Wai Keung Cheung[1], Ting-Chung Poon[2]; *[1]Dept .of Electronic Engineering, City Univ. of Hong Kong, Hong Kong; [2]Bradley Dept. of Electrical and Computer Engineering, Virginia Tech, USA.* A three-dimensional object scene is captured with a range camera. The recorded signal is enlarged, and converted in real-time into a Fresnel hologram with the integration of error diffusion, sub-lines, integrated Fresnel lines.

Coffee and Tea Break, *Convention Hall Foyer*
10:30-11:00

NOTES

DTuB • Novel Approaches in Digital Holography I
Tuesday, May 10, 2011
11:00–12:30
Kehar Singh; Indian Inst. of Technology, India, Presider

DTuB1 • 11:00 Invited
Wearable Head-up Display for Augmenting Visual Imagery, Lambertus Hesselink[1]; [1] *Stanford Univ., USA.* Abstract not available.

DTuB2 • 11:30
Holographic Control of Coherence and Polarization of Light, Rakesh K. Singh[1], Dinesh N. Naik[1], Hitoshi Itou[1], Yoko Miyamoto[1], Mitsuo Takeda[1]; [1]*Dept. of Information and Communication Engineering, Univ. of Electro-Communications, Japan.* We propose extension of coherence holographic technique to vectorial regime to control coherence and polarization of light. This is carried out using two computer generated holograms for orthogonally polarized components.

DTuB3 • 11:45
Two-Photon Excitation with Holographic Spatiotemporal Lens, Kouhei Kimura[1], Yoshinori Hashizume[1], Satoshi Hasegawa[1], Yoshio Hayasaki[1]; [1]*Utsunomiya Univ., Japan.* We demonstrate a holographic spatiotemporal lens composed of a diffraction grating and a chirped diffractive lens to improve an axial resolution of two-photon excitation. It generates the shortest pulse only at the focal plane.

DTuB4 • 12:00
The Space-Bandwidth Ratio, John J. Healy[1]; [1]*Computer Science, NUI Maynooth, Ireland.* The recently proposed space-bandwidth ratio defines how 'tall' a signal's phase space diagram is. Useful in choosing reconstruction algorithms in digital holography, here we propose its use for back-of-the-envelope calculations concerning lens system propagation.

DTuB5 • 12:15
Limitations of Coherent Computer Generated Holograms, Zhengyun Zhang[1], George Barbastathis[2], Marc Levoy[3]; [1]*Electrical Engineering, Stanford Univ., USA;* [2]*Mechanical Engineering, MIT, USA;* [3]*Computer Science, Stanford Univ., USA.* Full coherence places limitations on even two-dimensional intensity patterns, e.g. in a Fraunhoffer CGH setup. Consequences of this result, feasible coherent patterns and niceties of partial coherence will be explored.

12:30-13:15 Lunch Break, *Own your own*

NOTES

DTuC • Poster Session I, *Convention Hall Foyer*
Tuesday, May 10, 2011
13:15–14:30

DTuC1
Image Design for Normal Viewing Image-Plane Disk-type Multiplex Hologram, Chih-Hung Chen[1], Yih-Shyang Cheng[1]; [1]*NCU, Taiwan.* In this paper, the method of direct object-image relationship in normal-viewing disk-type multiplex holography is adopted for theoretical analysis. The parameters for both virtual-image and real-image generation are also introduced.

DTuC2
An Encryption Scheme Using a SLM-Based Hologram and a Talbot Phase Grating, Zhongyu Chen[1], Fung Jacky Wen[1], Po Shuen Chung[1]; [1]*Dept. of Electronic Engineering, City Univ. of Hong Kong, Hong Kong.* This scheme is composed of a computer-generated hologram on a spatial light modulator placed at a self-imaging distance from a binary Talbot phase grating. The scheme allows encryption of multi-images using multi-level Talbot grating array.

DTuC3
Widening of the Field of View in Parallel Two-Step Phase-Shifting Digital Holography, Peng Xia[1], Tatsuki Tahara[1], Yuki Shimozato[1], Takashi Kakue[1], Yasuhiro Awatsuji[1], Shogo Ura[1], Kenzo Nishio[2], Toshihiro Kubota[3], Osamu Matoba[4]; [1]*Graduate School of Science and Technology, Kyoto Inst. of Technology, Japan;* [2]*Advanced Technology Ctr., Kyoto Inst. of Technology, Japan;* [3]*Kubota Holography Lab. Corp., Japan;* [4]*Graduate School of System Informatics, Kobe Univ., Japan.* An algorithm for widening of the field of view in parallel two-step phase-shifting digital holography is proposed. Three kinds of the interpolations are applied to the hologram for reconstruction of the object wave.

DTuC4
Speckle Suppression in Holographic Projection Displays by Temporal Integration of Diffractive Optical Elements, Wei-Feng Hsu[1], Chuan-Feng Yeh[1]; [1]*Dept. of Electro-optical Engineering, Natl. Taipei Univ. of Technology, Taiwan.* Speckle of images in holographic projection displays was effectively suppressed by the temporal integration of a sequence of input diffractive optical elements which were selected on the correlation coefficients of their diffraction images.

DTuC5
Some Considerations when Numerically Calculating Diffraction Patterns, Damien P. Kelly[1], Nail Sabitov[1], Thomas Meinecke[1], Stefan Sinzinger[1]; [1]*Technical Ilmenau Univ. of Technology, Germany.* Numerical calculation of diffraction integrals remains a challenge in modern optics, with applications in digital holography and phase retrieval techniques. Two different numerical techniques are compared and the associated sampling rules derived.

DTuC6
Multi-View Image Reconstruction by Using Holographic Lens Array Recorded on Photopolymer, Keehoon Hong[1], Yongjun Lim[1], Byoungho Lee[1]; [1]*SNU, Republic of Korea.* We propose the integral imaging based on a holographic lens array. Recording and reconstruction schemes for holographic lens array are represented. The experimental results confirm the proposed system can reconstruct different view images.

DTuC7
Optical Reconstruction of Digital Hologram Using Spatial Light Modulator for Binocular Stereopsis, Yutaka Mori[1], Takanori Nomura[1]; [1]*Wakayama Univ., Japan.* Binocular stereopsis using digital holography is proposed. As a first stage of the digital holographic binocular stereopsis, optical reconstruction using a spatial light modulator is given.

DTuC • Poster Session I-Continued, *Convention Hall Foyer*
Tuesday, May 10, 2011
13:15–14:30

DTuC8
Single-Shot Phase-Shifting Digital Holography Based on the Spatial Carrier Interferometry, Yasuhiro Harada[1]; [1]*Computer Science, Kitami Inst. of Technology, Japan.* Phase-shifting digital holography which is available simply with single-shot exposure of holograms without any special phase-shifting device is proposed.

DTuC9
3-D Imaging Based on Full Analytical Fraunhofer CGH, Yuan-Zhi Liu[1], Jian-Wen Dong[1], Yi-Ying Pu[1], Bing-Chu Chen[1], He-Xiang He[1], He-Zhou Wang[1], Huadong Zheng[2], Yingjie Yu[2]; [1]*State Key Lab. of Optoelectronic Materials and Technologies, Sun Yat-sen Univ., China;* [2]*Dept. of Precision Mechanical Engineering, Shanghai Univ., China.* Fraunhofer-CGH proves to be valid in Fresnel region for display and have the same performance as Fresnel-CGH. An analytical Fraunhofer method is proposed for holographic computation of 3-D triangle-mesh-model. Experiment reveals high quality results.

DTuC10
Realtime 3-D Profilometer Using GPU and Multicore CPU, Yoko Miyamoto[1], Atsushi Wada[2], Takuro Iizuka[1], Tomoya Suzuki[1], Tomoaki Nakayama[1], Keiichi Yanagawa[1], Shunsuke Aoki[1], Yusuke Ozaki[1], Taiga Toriu[1], Masaru Kawana[1], Tetsuro Nishino[1], Mitsuo Takeda[1]; [1]*Univ. of Electro-Communications, Japan;* [2]*Dept. of Communications Engineering, Natl. Defense Academy, Japan.* We propose a realtime 3D profilometer using both a graphics processing unit (GPU) and a multicore central processing unit (CPU). The GPU extracts phase from fringe patterns, and phase unwrapping is done on the CPU.

DTuC11
Time-Division Color Electro-Holography with Low-Price Microprocessor, Minoru Oikawa[1], Takuto Yoda[1], Tomoyoshi Shimobaba[1], Nobuyuki Masuda[1], Tomoyoshi Ito[1]; [1]*Graduate school of Engineering, Chiba Univ., Japan.* We propose time-division based color electro-holography with a low-priced microprocessor. The proposed method reduces the development cost using a low-priced microprocessor and RS232C.

DTuC12
Information Encryption Using Arbitrary Two-Step Phase-Shift Interferometry, Chi-Ching Chang[1], Min-Tzung Shiu[1], Wang-Ta Hsieh[1], Je-Chung Wang[1]; [1]*Electro-Optical and Energy Eng., Ming Dao Univ., Taiwan.* The principle of encryption and decryption which is using a lenticular lens array (LLA) as a key in arbitrary unknown TSPSI is given. The encrypted image can be numerically and successfully decrypted by the arbitrary unknown TSPSI with right key.

DTuC13
Analysis of Reconstruction Characteristics in Fluorescence Digital Holography, Yoshiki Tone[1], Kouichi Nitta[1], Osamu Matoba[1], Yasuhiro Awatsuji[2]; [1]*Grad. School of System Informatics, Kobe Univ., Japan;* [2]*Division of Electronics, Kyoto Inst. of Technology, Japan.* One of the important applications of digital holography is a fluorescence three-dimensional microscopy. We analyze the influence of spatial coherence degree to the reconstructed quality of 3D profiles in fluorescence digital holography.

DTuC14
Generation of Phase-only Wavefront Data for Wide Field of View by Polygon-based CGH, Nozomu Ueda[1], Kouichi Nitta[1], Osamu Matoba[1]; [1]*Grad. School of System Infromatics, Kobe Univ., Japan.* We present a method to generate the phase-only wavefront data for wide field of view by using polygon-based CGH method. Numerical and experimental verification are demonstrated.

DTuC15
Holographic Imaging of Laser-Induced Patterns In Nanofluids and Oil-in-Water Emulsions, Nickolai Kukhtarev[1], Tatiana Kukhtareva[1], Sonia Gallegos[2]; [1]*Physics, AAMU, USA;* [2]*Oceanography Division, Naval Res. Lab, USA.* Laser-induced pattern formations were observed in crude oil emulsions and in nanofluids. Self-imaging of the dynamic patterns reveal quasi-periodic time dependence of brightness during CW laser illumination, induced by photo-thermal gradients.

DTuC16
Real-Time Lensless Image Projection by Electroholography with Amplitude-Phase Modulation, Michal Makowski[1], Andrzej Siemion[1], Izabela Ducin[1], Karol Kakarenko[1], Maciej Sypek[1], Agnieszka Siemion[1], Jaroslaw Suszek[1], Dariusz Wojnowski[1], Andrzej Kolodziejczyk[1]; [1]*Faculty of Physics, Warsaw Univ. of Technology, Poland.* We present a compact lensless projection of animated color images based on real-time computer-generated Fourier holograms. Amplitude and phase modulation of three primary-colored laser beams is done by a matched pair of spatial light modulators.

DTuC17
Three-Dimensional Imaging by Portable Parallel Phase-Shifting Digital Holography System, Motofumi Fujii[1], Takashi Kakue[1], Peng Xia[1], Kenichi Ito[1], Tatsuki Tahara[1], Yuki Shimozato[1], Yasuhiro Awatsuji[1], Kenzo Nishio[2], Shogo Ura[1], Toshihiro Kubota[3], Osamu Matoba[4]; [1]*Graduate School of Science and Technology, Kyoto Inst. of Technology, Japan;* [2]*Advanced Technology Center, Kyoto Inst. of Technology, Japan;* [3]*Kubota Holography Lab. Corp., Japan;* [4]*Graduate School of System Informatics, Kobe Univ., Japan.* We constructed a portable parallel phase-shifting digital holography system. The size and weight of the system are 450mm × 250mm × 200mm and 7kg, respectively. We succeed in three-dimensional imaging of objects with the system.

DTuC18
Angle-by-Angle Reconstruction of Three-Dimensional Volumetric Information Using Computational Integral Imaging, Mu-Chieh Lo[1], Gilbae Park[2], Byoungho Lee[2], Guo-Dung John Su[1]; [1]*Graduate Inst. of Photonics and Optoelectronics, Natl. Taiwan Univ., Taiwan;* [2]*School of Electrical Engineering, Seoul Natl. Univ., Republic of Korea.* A computational reconstruction technique with variable viewing angles is proposed, which simulates non-parallel reconstution planes. Experimental results support the validity that the image is reconstructed only at the exact angular position.

DTuC19
Four-Primary-Color Digital Holography, Yuki Shimozato[1], Yasunori Ito[1], Tatsuki Tahara[1], Takashi Kakue[1], Yasuhiro Awatsuji[1], Shogo Ura[1], Kenzo Nishio[2], Toshihiro Kubota[3], Osamu Matoba[4]; [1]*Graduate School of science and Technology, Kyoto Inst. of Technology, Japan;* [2]*Advanced Technology Center, Kyoto Inst. of Technology, Japan;* [3]*Kubota Holography Lab. Corp., Japan;* [4]*Graduate School of System Informatics, Kobe Univ., Japan.* We propose a color digital holography using four recording wavelengths and estimation for accurate color reproduction of a 3-D object. The validity of the technique was numerically confirmed. Also the technique was experimentally demonstrated.

DTuC20
Human Eye Detection by Volume Holographic Imaging Elements for See-through type Glasses, Yukako Takizawa[1], Yoichi Kitagawa[1], Tetsuya Matsumoto[1], Hisanori Miura[1], Akio Mizuno[2], Takaharu Sato[3], Osamu Matoba[3]; [1]*Hyogo Prefectural Institute of Technology, Japan;* [2]*Kyowa Electronics Co., Ltd, Japan;* [3]*Kobe Univ., Japan.* Human-eye detection is demonstrated by volume holographic imaging elements (VHIEs) for see-through-type glasses. A VHIE is integrated with imaging function and background noise reduction filter for imaging under white light illumination.

DTuC21
Fast Recurrence Algorithm for Computer-Generated-Hologram, Jian Tong Weng[1], Tomoyoshi Shimobaba[1], Minoru Oikawa[1], Nobuyuki Masuda[1], Tomoyoshi Ito[1]; [1]*Graduate school of Engineering, Chiba Univ., Japan.* This paper presents a fast recurrence algorithm for a computer-generated-hologram (CGH). The recurrence algorithm based on Taylor expansion can reduce the number of cosine computations in the CGH equation.

DTuC • Poster Session I-Continued, *Convention Hall Foyer*
Tuesday, May 10, 2011
13:15–14:30

DTuC22
Augmented Reality System Based on Integral Floating Method, Junghun Jung[1], Jisoo Hong[2], Byoungho Lee[2], Sung-Wook Min[1]; [1]*Dept. of Information Display, Kung Hee Univ., Republic of Korea;* [2]*School of Electrical Engineering, Seoul National Univ., Republic of Korea.* We propose augmented reality system based on the integral floating method, which uses the integral imaging system with floating lens. The basic experiments were performed to prove the feasibility of the proposed system.

DTuC23
Holographic Microscope by One-Shot Digital Holography, Mayu Otani[1], Kunihiro Sato[1]; [1]*Dept. of Electrical Eng. and Computer Science, Univ. of Hyogo, Japan.* A holographic microscope is developed by applying one-shot digital holography. Resolution higher than 1μm is obtained, and high-resolution images with no distortion can be observed for objects immersed in the liquid or in the solid.

DTuC24
Single-Shot Normal Incidence Imaging Ellipsometer Based on Polarized Dual-Reference Wave Scheme, Daesuk Kim[1], Hyunsuk Kim[1], Dahi Abdelsalam[1,2], Dugargaramjav Tserendolgor[1,3], Byunjoon Baek[1]; [1]*Mechanical System Engineering, Chonbuk Natl. Univ., Republic of Korea;* [2]*Engineering and Surface Metrology Lab, Natl. Inst. of Standard, Egypt;* [3]*Power Engineering School, Mongolian Univ. of Science and Technology, Mongolia.* The proposed scheme can provide a very fast solution for featuring the nano pattern 3-D objects.

DTuC25
Cell Death and Ionic Regulation Detection with Digital Holographic Microscopy, Nicolas Pavillon[1], Jonas Kühn[1,2], Pascal Jourdain[3], Christian D. Depeursinge[1], Pierre J. Magistretti[2,3], Pierre Marquet[2,3]; [1]*STI, Ecole Polytechnique Fédérale de Lausanne, Switzerland;* [2]*Dépt. de Psychiatrie, Ctr. Hospitalier Univ. Vaudois, Switzerland;* [3]*Brain Mind Inst., Ecole Polytechnique Fédérale de Lausanne, Switzerland.* We demonstrate the capability of digital holographic microscopy to detect cell death through the measurement of volume regulation, considered as an early indicator of cellular deregulation, leading to cell death, and link it with calcium homeostasis.

DTuC26
Resolution Analysis of Digital Holography by Wigner Distribution, Hao Yan[1], Anand Asundi[1]; [1]*Nanyang Technological Univ., Singapore.* Resolution of digital holography limited by pixel averaging effect within the finite detection size of single pixel, finite CCD aperture size limitation, sampling effect and object extent is investigated by Wigner distribution.

DTuC27
Wall Turbulence Measurements using Side-Scattering Digital Holographic Particle Image Velocimetry, Michel Stanislas[2], Juliana K. Abrantes[1,2], Luis Fernando A. Azevedo[1], Sébastien Coudert[2]; [1]*Mechanical Engineering, PUC-Rio, Brazil;* [2]*Lab. de Mécanique de Lille, Univ. Lille1, France.* DHPIV is employed in a setup that enables 3-D flow measurements in the wall region of a large wind tunnel. Results show that axial accuracy in detection of in-focus position of particles is improved by the presence of a microscope objective.

DTuC28
An Optical Sectioning Microscope with a Holographic Optical Element Based Beam Scanning, Bosanta R. Boruah[1], Abhijit Das[1]; [1]*Physics, IIT Guwahati, India.* Here we describe a scanning microscope having optical sectioning capability, using a dynamic holographic optical element based beam scanning mechanism. We discuss the advantages of the technique and present some preliminary experimental results.

DTuC29
Optimum Threshold for Digital Holographic Particle Field Characterization, Dhananjay K. Singh[1], Padipta K. Panigrahi[1]; [1]*Mech. Engineering, I I T Kanpur, India.* The present study reports the effectiveness of a novel threshold technique for proper segmentation of particle images from background. Both simulated and experimental holograms are used to demonstrate the importance of proper threshold.

DTuC30
Using a Dual-wavelength Source for Depth Resolution Enhancement in Optical Scanning Holography, Jun Ke[1], Edmund Y. Lam[1]; [1]*Univ. of Hong Kong, Hong Kong.* We use a wavelength selectable source to demonstrate depth resolution enhancement in an optical scanning holography system. Sectional objects separated by 2.5µm in the axial direction are reconstructed with a Fourier-domain conjugate gradient method.

DTuC31
Withdrawn

DTuC32
Measurement of Young's Modulus of Polyacrylamide Gel by Digital Holography, Xiao Yu[1], Changgeng Liu[1], David C. Clark[1], Myung K. Kim[1]; [1]*Physics, Univ. of South Florida, USA.* A convenient technique is introduced for measuring the Young's modulus of soft material (polyacrylamide gel) for cellular adhesion with the principles of digital holography.

DTuC33
Four-Dimensional Imaging by Parallel Phase-Shifting Digital Holographic Microscopy, Tatsuki Tahara[1], Takashi Kakue[1], Yasuhiro Awatsuji[1], Kenzo Nishio[2], Shogo Ura[1], Toshihiro Kubota[3], Osamu Matoba[4]; [1]*Graduate school of Science and Technology, Kyoto Inst. of Technology, Japan;* [2]*Advanced Technology Ctr., Kyoto Inst. of Technology, Japan;* [3]*Kubota Holography Lab. Corp., Japan;* [4]*Graduate School of System Informatics, Kobe Univ., Japan.* We present the imaging of the temporal change of three-dimensional movement and um-order structure in the microscopic area by using parallel phase-shifting digital holography. The effectiveness of the technique was verified by an experiment.

DTuC34
Acquisition and Visualization of Dynamic 3-D Scene, Yong Li[1], Shijiang Lu[1], Fang Song[2], Zhiqiang Gao[1], Hongzhen Jin[1], Hui Wang[1]; [1]*Inst. of Information Optics, China;* [2]*Inst. of Command and Technology, PLA, China.* 3-D image with texture is captured with high-speed 3D scanner in which π phase-shifting FTP and an encoded pattern are adopted. The CGH is used for 3D visualization of the measured data.

DTuC35
Color Holographic Projection with Space-Division Method, Tomoyoshi Shimobaba[1], Takayuki Takahashi[2], Nobuyuki Masuda[1], Tomoyoshi Ito[1]; [1]*Graduate school of Engineering, Chiba Univ., Japan;* [2]*Yamagata Univ., Japan.* We propose a color holographic projection with space-division method, which records a color information on a hologram by dividing and distributing each color channel in space.

DTuC36
Super-resolution in Digital Holography via Nonlinearity, Christopher Barsi[1], Jason W. Fleischer[1]; [1]*Electrical Engineering, Princeton Univ., USA.* Like all linear techniques, digital holography suffers from limited resolution due to finite-aperture effects. We show here that nonlinearity breaks down linear limits, formulated by Abbe, as high-frequency spatial modes mix with low-frequency ones.

DTuC37
Weighting Iterative Fourier Transform Algorithm for Kinoform Implemented with Phase-Only SLM, Alaxander Kuzmenko[3], Pavlo Iezhov[2], Jin-Tae Kim[1]; [1]*Dept. of Photonic Eng., Chosun Univ., Republic of Korea;* [2]*Inst. of Applied Optics, Ukraine;* [3]*Institute of Physics, Ukraine.* A procedure to introduce carrier frequency into the structure of a kinoform is proposed. The advantages of proposed method compared with other methods are confirmed by model and experiment by using a phase only SLM.

DTuC38
Paint Drying Process Monitored by Digital Holography and Estimation of Tack-free Time, Masayuki Yokota[1], Tomoaki Kawakami[1], Yoshiki Kimoto[1]; [1]*Shimane Univ., Japan.* A paint drying process is assessed by digital holography. Quantitative analysis using the reconstructed complex amplitudes of the light from the paint surface is performed and the time of tack-free drying under different temperature is investigated.

DTuC39
Measurement of Light-induced Refractive Index Change in Photopolymer with Quantitative Phase Microscopy, Wataru Watanabe[1], Hidenobu Arimoto[1], Kazuyoshi Masaki[2], Takashi Fukuda[1]; [1]*Photonics Research Inst., AIST, Japan;* [2]*Nippon Steel Chemical Co. Ltd, Japan.* We present quantitative phase measurements of light-induced refractive index changes in photopolymer by digital holographic microscopy.

DTuD • Novel Approaches to Digital Holography II
Tuesday, May 10, 2011
14:30–16:30
Thomas Naughton; Univ. Ouluu, Finland, Presider

DTuD1 • 14:30 Invited
Low Bit-rate Compression of Computer-Generated Fresnel Holograms based on Vector Quantization, Peter W. Tsang[1], Wai Keung Cheung[1], Ting-Chung Poon[2]; [1]*Electronic Engineering, City Univ. of Hong Kong, Hong Kong;* [2]*Electrical and Computer Engineering, Virginia Tech, USA.* We propose a method for compressing computer-generated complex Fresnel hologram based on vector quantization. The compression ratio can exceed 1000 times, and still preserves acceptable visual quality on the reconstructed images.

DTuD2 • 15:00
Transport of Intensity Imaging Applied to Quantitative Optical Phase Tomography, Justin W. Lee[1], Jason Ku[1], Laura Waller[1,3], George Barbastathis[1,2]; [1]*MIT, USA;* [2]*Singapore-MIT Alliance for Research and Technology, Natl. Univ. of Singapore, Singapore;* [3]*Princeton Univ., USA.* A bulk phase object is imaged tomographically and reconstructed using transport of intensity principles. The resulting object reconstruction shows good agreement with the actual object.

DTuD3 • 15:30
Compressive Phase Space Tomography, Lei Tian[1], Justin Lee[1], Se Baek Oh[1], George Barbastathis[1,2]; [1]*Mechanical Engineering, Massachusetts Institute of Technology, USA;* [2]*Singapore-MIT Alliance for Research and Technology (SMART) Centre, Singapore.* We apply compressive sensing to retrieve coherence quantities in phase space tomography. Examples are given to show significant improvement in the recovery result.

DTuD4 • 15:45
Digital Holography by Ghost Imaging, Pere Clemente[1,2], Vicente Durán[1,3], Enrique Tajahuerce[1,3], Víctor Torres-Company[4], Raúl Martínez-Cuenca[1,3], Jesús Lancis[1,3]; [1]*Inst. of New Imaging Technologies, Univ. Jaume I, Spain;* [2]*Servei Central d'Instrumentció Científica, Univ. Jaume I, Spain;* [3]*Physics Dept., Univ. Jaume I, Spain;* [4]*School of Electrical Engineering, Purdue Univ., USA.* We present a method to perform digital holography by using a single pixel detector. It is based on combining computational ghost imaging and phase-shifting interferometry.

DTuD5 • 16:00
Wavefront Sensing with a Flexible Detector Geometry Using an Array of Binary Holograms, Bosanta R. Boruah[1], Abhijit Das[1]; [1]*Physics, IIT Guwahati, India.* Here we describe a zonal wavefront sensing technique that facilitates flexible detector geometry, using an array of binary amplitude holograms. The technique can provide better measurement accuracy and help in the miniaturization of the device.

Coffee and Tea Break, *Convention Hall Foyer*
16:15-16:45

DTuE • Tutorial Session
Tuesday, May 10, 2011
16:45–19:00

DTuE1 • 16:45 Tutorial
Compressive Holography, David J. Brady[1]; [1] *Duke Univ., USA.* This tutorial briefly reviews the history and theory of compressive measurement and explains may be applied in holographic systems to achieve snapshot diffraction tomography and wide field sparse aperture imaging.

DTuE2 • 17:30 Tutorial
Coherence Holography: A Tutorial Review, Mitsuo Takeda[1]; [1]*Dept. of Engineering Science, Univ. of Electro-Communications, Japan.* A tutorial review will be given on the principle and applications of a recently proposed unconventional holography technique, coherence holography, and a related technique for dispersion-free 3-D coherence imaging based on a spatial frequency comb.

DTuE3 • 18:15 Tutorial
Three Dimensional Sensing, Visualization, and Display by Integral Imaging , Bahram Javidi[1], Manuel Martinez-Corral[1]; [1]*ECE, Univ. of Connecticut, USA.* This tutorial will presents an overview of our recent work in three dimensional (3-D) sensing, visualization, and display by integral imaging. Theoretical and experimental results, various applications, and technical challenges will be discussed.

Welcome Reception, *Convention Hall Foyer*
18:30-19:30

NOTES

DWA • Entrepreneurship in Optics
Wednesday, May 11, 2011
09:00–10:30
Partha P. Banerjee; Univ. of Dayton, USA, Presider

DWA1 • 09:00 Invited
Materials and Technology for Polarization Holography and Diffractive Waveplates, Nelson V. Tabirian[1], Sarik R. Nersisyan[1], Diane M. Steeves[2], Brian R. Kimball[2]; [1]*BEAM Engineering for Advanced Measurements Co., USA;* [2]*US Army Natick Soldier Res., Development and Engineering Center, USA.* The principles of polarization holography and recent advances in materials and technology are reviewed. High efficiency and spectrally and angularly broadband diffraction inherent to polarization gratings challenges Bragg gratings for many applications opening new prospects.

DWA2 • 09:30 Invited
Development and Factors of the Technology Commercialization on Holography Application, Takahiro Ikeda[1]; [1]*Pi Photonics, Inc., Japan.* Pi Photonics, Inc. is the venture company from Hamamatsu. We provide you 'PiP' which means Products integrated Photonics. We introduce our products are QPM system integrated with quantitative phase imaging unit and HOLORER-it! LED lighting.

DWA3 • 10:00
Real-Time 3D Sensing Using a Stacked Color Image Sensor, Pascal Picart[1,2], Patrice Tankam[1], Qinghe Song[1,3], Junchang Li[3,1], Jean-Michel Desse[4]; [1]*LAUM CNRS, France;* [2]*ENSIM, France;* [3]*KUST, China;* [4]*ONERA, France.* We present real-time three-dimensional sensing based on digital three color holography. The colors are simultaneously recorded by a stacked image sensor and an algorithm with adjustable magnification provides real time full field 3D measurements.

DWA4 • 10:15
25 Hz en-face Low-Coherent Quantitative Reflection Phase Imaging of Living Cells, Toyohiko Yamauchi[1], Hidenao Iwai[1], Yutaka Yamashita[1]; [1]*Hamamatsu Photonics, Japan.* The surface motion of a living cell is imaged in 25 Hz frame rate. The setup is based on an interference microscope with sub-nanometer optical-path length control.

Coffee and Tea Break, *Own your own*
10:30-11:00

NOTES

DWB • Digital Holography in Metrology and Manipulation
Wednesday, May 11, 2011
11:00–12:30
Peter Tsang; City Univ. Hong Kong, China, Presider

DWB1 • 11:00 Invited
Optimal focusing *in situ*: New Routes for Optical Trapping and Biophotonics, Tomas Cizmar[1,2], Michael Mazilu[2], Kishan Dholakia[2]; [1]*School of Medicine, Univ. of St Andrews, UK;* [2]*School of Physics and Astronomy, Univ. of St Andrews, UK.* We present a method to eliminate optical aberrations originating in microscopic biological samples allowing one to restore the optimal focusing of lasers in situ after propagating through turbid media. We discuss possible applications in Biophotonics.

DWB2 • 11:30
Decoupling of Thermal Effects to Image Nanometric Optical Pressure Deformation by Digital Holography, David C. Clark[1], Myung K. Kim[1]; [1]*Physics, Univ. of South Florida, USA.* It is evident that thermal effects should not be dismissed when pursuing optical radiation pressure experiments even for transparent media. We have developed a unified model and simulated and tested methods of decoupling the two effects.

DWB3 • 11:45
Measurement of Displacement for Diffuse Object Using Phase-shifting Digital Holography with 4-Bucket Method and Polarization Imaging Camera, Tomohiro Kiire[1], Suezou Nakadate[2], Masato Shibuya[2], Toyohiko Yatagai[1]; [1]*Ctr. for Optical Res. and Education, Utsunomiya Univ., Japan;* [2]*Dept. of Media and Image Technology, Tokyo Polytechnic Univ., Japan.* Displacement for diffuse object can be measured from two Fourier transforms of phase holograms which are calculated with four quadrature phase-shifted hologram data obtained by a polarization imaging camera before and after the object movement.

DWB4 • 12:00
Inertial Migration of Spherical Particles in Micro-scale Flows Measured by In-line Digital Holographic Microscopy, Yong-Seok Choi[1], Sang-Joon Lee[1]; [1]*Mechanical Engineering, Pohang Univ. of Science and Technology (POSTECH), Republic of Korea.* In-line digital holographic microscopy technique is used for measuring the inertial migration of particles suspended in micro-scale flows of circular tube and square microchannel. The results give new insight into the inertial migration phenomena.

DWB5 • 12:15
Near Wake Flow of Cylinder Analyzed by 3λ DHI, Jean-Michel Desse[1], Pascal Picart[2], Patrice Tankam[2]; [1]*ONERA, France;* [2]*LAUM, France.* The unsteady near wake flow of circular cylinder is analyzed by digital 3λ holographic interferometry at Mach 0.45 in order to yield the time evolution of unstantaneous gas density fields.
Convention Hall Foyer

12:30-13:15 Lunch Break, *Own your own*

DWC • Poster Session II
Wednesday, May 11, 2011
13:15–14:30

DWC1
Anomalous Refractive Effects in Photonic Crystals Formed by Holographic Lithography, Guoyan Dong[1], Xiulun Yang[2], Luzhong Cai[2]; [1]*Tsinghua Univ., China;* [2]*Shandong Univ., China.* Anomalous refractive effects of PhCs formed by holographic lithography can be modulated more easily than regular PhCs. The unique features extend the possibly guiding ability of holographic PCW and promising potential in optical application.

DWC2
Imaging Past Obstructions, Jonathan Petruccelli[1], Lei Tian[2], Liu Xiaogang[3], George Barbastathis[1,2]; [1]*SMART Centre, Singapore;* [2]*Dept. of Mechanical Engineering, MIT, USA;* [3]*Dept. of Physics, Univ. of Cambridge, UK.* The optical detection of a disk geometrically obscured by a second disk and illuminated by a plane wave is considered. Auto and cross-correlation comparisons are found to yield good detection capability.

DWC3
Phase-Space Imaging of Partially Coherent beams with a Spatial Light Modulator, Laura Waller[1], Guohai Situ[1], Jason W. Fleischer[1]; [1]*Electrical Engineering, Princeton Univ., USA.* We develop an imaging system for measuring the local coherence length of partially coherent light beams. The 4-D phase-space distributions are captured by scanning and Fourier-transforming an aperture created by a spatial light modulator(SLM).

DWC4
Adaptive Holographic Femtosecond Laser Processing, Satoshi Hasegawa[1], Yoshio Hayasaki[1]; [1]*Ctr. for Optical Res. and Education, Utsunomiya Univ., Japan.* In order to fabricate a huge number of the processing points simultaneously and precisely in holographic femtosecond laser processing, an adaptive control technique was applied to holographic femtosecond laser processing.

DWC5
Digital Color Management in Holoprinter, Fei Yang[1], Koki Wakunami[1], Kazuma Shinoda[1], Noriaki Hashimoto[1], Masahiro Yamaguchi[1]; [1]*Imaging Science and Engineering Lab., Tokyo Inst. of Technology, Japan.* We applied digital color management by holoprinter, which produces full-color full-parallax hologram. The color reproducibility was tested by printing color chart hologram, and the CIELAB ΔE is fairly small.

DWC6
Improvements to 4f Imaging System Used for Hologram Reconstruction, Takayuki Kurihara[1], Yasuhiro Takaki[1]; [1]*Institute of Engineering, Tokyo University of Agriculture and Technology, Japan.* A 4f imaging system was improved by shifting a Fourier transform lens to correct viewing region distortion, and placing a lens on the image plane to maximize the viewing region. Experimental verifications are described.

DWC7
Viewing Angle Enhanced Integral Imaging by Using Rhombus Shape Elemental Image, Shin Seung-Ho[1], Jae-Young Jang[1]; [1]*Physics, Kangwon Natl. Univ., Republic of Korea.* A viewing angle enhanced integral imaging system based on the lens switching method is proposed. The experimental results show that the display produces two times larger viewing angle than the conventional method.

DWC8
Influence of Pixel Saturation in Digital Holography, Pascal Picart[1,2], Patrice Tankam[1], Qinghe Song[3,1]; [1]*LAUM CNRS, France;* [2]*ENSIM, France;* [3]*KUST, China.* This paper proposes a theoretical and experimental analysis of the saturation effect in digital Fresnel holography and generalizes the linear image formulation to the case of the non linear pixel saturation.

DWC9
Holographic Recording of Vertical Surfaces, Florian B. Soulard[1], Richard McWilliam[1], Joshua J. Cowling[1], Alan Purvis[1], Gavin L. Williams[2], N. L. Seed[2], Jesus J. Toriz-Garcia[2], Peter A. Ivey[3]; [1]*Engineering and Computing Sciences, Durham Univ., UK;* [2]*Electronic and Electrical Engineering, Sheffield Univ., UK;* [3]*Innotec Ltd., UK.* A method is presented for recording horizontal and vertical surfaces in a single process with a standard DHM set-up. The purpose is to avoid rotating the sample, which would require new alignment and calibration procedures.

DWC10
Single-Exposure Phase-Shifting Digital Holography Using Random Phase Reference Wave, Masatoshi Imbe[1], Takanori Nomura[1]; [1]*Wakayama Univ., Japan.* Single-exposure phase-shifting digital holography using random phase reference wave is proposed. Two types of algorithms for obtaining the fully-complex field of the object wave are introduced.

DWC11
Phase-only Wavefornt Reconstruction of 3-D Objects with Wide Field of View, Masa Tanaka[1], Kouichi Nitta[1], Osamu Matoba[1]; [1]*Grad. School of System Infromatics, Kobe Univ., Japan.* We demonstrate experimentally a phase-only reconstructing 3-D display in a spatial light modulator for wide field of view by using tilted illumination. The decrease of the unwanted spatial shift is also confirmed experimentally.

DWC12
Simultaneous Two-Wavelength Digital Holography and Its Application to Surface Shape Measurement, Daisuke Barada[1,2], Tomohiro Kiire[2], Jun-ichiro Sugisaka[2], Shigeo Kawata[1,2], Toyohiko Yatagai[2,1]; [1]*Graduate School of Engineering, Utsunomiya Univ., Japan;* [2]*Ctr. for Optical Res. and Education (CORE), Utsunomiya Univ., Japan.* Two-wavelength digital holography with Doppler-phase shifting method was proposed. Two laser beams with different wavelength was simultaneously illuminated onto a target object, and the surface shape was reconstructed from the digital holograms.

DWC13
Infrared Digital Holography for Large Object Investigation, Andrea Geltrude[1], Massimiliano Locatelli[1], Riccardo Meucci[1], Anna Pelagotti[1], Melania Paturzo[2], Pasquale Poggi[1], Pietro Ferraro[2]; [1]*CNR-INO, Italy;* [2]*CNR-INO, Italy.* Digital Holography in the infrared range presents some advantages compared with the visible range. A much higher stability, a wider view angle and shorter acquisition distances are achievable, allowing easier acquisition of large object holograms

DWC14
Digital Holographic Profilometry Applied to an Inspection of a Pipe Inner Surface, Masayuki Yokota[1], Toru Adachi[1]; [1]*Shimane Univ., Japan.* Digital holography has been applied to a measurement of an inner surface profile of a pipe. The shape of two pieces of metal sheet pasted on the inner surface and a hole made in the wall can be detected and evaluated with a digital image processing.

DWC15
Three-Dimensional Position Measurement of Nanoparticles in a Liquid under Light Potential Using in-Line Digital Holography, Takayuki Higuchi[1], Hisao Fukaya[1], Pham D. Quang,[1], Satoshi Hasegawa[1], Yoshio Hayasaki[1]; [1]*Utsunomiya Univ., Japan.* A three-dimensional movement of nanoparticles in a liquid under light potential formed by a focused beam was measured with a digital holographic microscope, which is an in-line type with a green light emitting diode.

DWC16 • 13:15
Holographic Second Harmonic Generation Imaging, Etienne Shaffer[1], Pierre Marquet[1,2], Christian D. Depeursinge[1]; [1]*École Polytechnique Fédérale de Lausanne (EPFL), Switzerland;* [2]*Dépt. de Psychiatrie-CHUV, Site de Cery, Switzerland.* Nonscanning holographic second harmonic generation (SHG) imaging retrieves both the amplitude and the phase of SHG. We present an overview of the technique and its applications for tracking of nanoparticles and SHG phase contrast imaging.

DWC • Poster Session II-Continued
Wednesday, May 11, 2011
13:15–14:30

DWC17 • 13:15
Depth Perception with See-Through Holographic Display, Mitsuru Kitamura[1], Akiko Kitamura[1], Tomoki Yasuda[1], Masachika Watanabe[1]; [1]*Res. and Development Center, Dai Nippon Printing Co., Ltd., Japan.* The depth perception of three-dimensional images was evaluated with see-through holographic display. In our experimental conditions, the influence of visual angle of the image is greater than that of accommodation in the depth perception.

DWC18
***In vitro* Topography of Living Cells Using Digital Holographic Microscopy,** Han-Yen Tu[1], Chau-Jern Cheng[2], Xin-Ji Lai[2], Hsing-Jung Chen[3]; [1]*Electronic Engineering, St. John's Univ., Taiwan;* [2]*Electro-Optical Science and Technology, Natl. Taiwan Normal Univ., Taiwan;* [3]*Life Science, Natl. Taiwan Normal Univ., Taiwan.* This work presents a measurement and analysis approach for in vitro topography of living cells by digital holographic microscopy. Experimental results and related theoretical study are described in this report.

DWC19
Michelson Interferometer-Based Digital Holographic Microscopy for Inspection of Technical Phase Specimens and Quantitative Live Cell Imaging, Bjoern Kemper[1], Frank Schlichthaber[1], Angelika Vollmer[1], Steffi Ketelhut[1], Christina E. Rommel[2], Sabine Przibilla[1], Jürgen Schnekenburger[2], Gert von Bally[1]; [1]*Ctr. for Biomedical Optics and Photonics, Univ. of Muenster, Germany;* [2]*Dept. of Medicine B, Univ. of Muenster, Germany.* A Michelson interferometer-based digital holographic microscopy (DHM) approach for quantitative phase imaging is presented. The method requires only an object illumination wave and simplifies the integration of DHM in common research microscopes.

DWC20
Fast Calculation of Fresnel Diffraction Calculation Using AMD GPU and OpenCL, Takashi Nishitsuji[1], Tomoyoshi Shimobaba[1], Takahiro Sakurai[1], Naoki Takada[2], Nobuyuki Masuda[1], Tomoyoshi Ito[1]; [1]*Graduate school of Engineering, Chiba Univ., Japan;* [2]*Shohoku College, Japan.* This paper presents a fast calculation of Fresnel diffraction, which is used for various optics calculation with a GPU made by AMD and OpenCL. The maximum computational speed is about 15 times faster than a CPU.

DWC21
Parallel Phase-Shifting Digital Holography Using Femtosecond Laser Pulse, Takashi Kakue[1], Motofumi Fujii[1], Peng Xia[1], Tatsuki Tahara[1], Yasuhiro Awatsuji[1], Kenzo Nishio[2], Shogo Ura[1], Toshihiro Kubota[3], Osamu Matoba[4]; [1]*Graduate School of Science and Technology, Kyoto Inst. of Technology, Japan;* [2]*Advanced Technology Ctr., Kyoto Inst. of Technology, Japan;* [3]*Kubota Holography Lab. Corp., Japan;* [4]*Graduate School of System Informatics, Kobe Univ., Japan.* We developed a camera having the image sensor on which the phase-shifting array device suitable for near-infrared light was attached, and succeeded in parallel phase-shifting digital holography using ultrashort laser pulses of 96 fs duration.

DWC22
Phase Amplification in Fringe Projection Topography and Digital Holography, Toyohiko Yatagai[1]; [1]*Ctr. for Optical Research and Education, Utsunomiya Univ., Japan.* Nonlinear fringe detection in fringe-projection topography and digital holograms generates non-sinusoidal fringe profile. Amplified phase is calculated using non-sinusoidal fringe spectrum.Theory and experiments are presented.

DWC23
Alternative Models of the Rotating Beam, Roarke Horstmeyer[1], Se Baek Oh[2], Ramesh Raskar[1], Hanhong Gao[2]; [1]*Media Lab, MIT, USA;* [2]*Mechanical Engineering, MIT, USA.* Rotating beams are usually analyzed with a Gauss-Laguerre modal decomposition. We examine rotating beam generation from a modeling perspective, using phase-retrieval algorithms and Hamiltonian raytracing, adding flexibility to the design process.

DWC24
Time-Resolved Interferometric Quantitative Observation of Femtosecond Laser Induced Phenomena in Glass under Tight Focusing and Near Threshold Energy, Keisuke Iwata[1], Satoshi Hasegawa[1], Akihiro Takita[1], Yoshio Hayasaki[1]; [1]*Utsunomiya Univ., Japan.* Femtosecond laser-induced phenomena including generation and diffusion of carriers and local heatup, generation and propagation of pressure waves, and formation of refractive index changes are measured by a pump-prope interference microscope.

DWC25
262500-Frames-Per-Second Phase-Shifting Digital Holography, Takashi Kakue[1], Motofumi Fujii[1], Yuki Shimozato[1], Tatsuki Tahara[1], Yasuhiro Awatsuji[1], Kenzo Nishio[2], Shogo Ura[1], Toshihiro Kubota[3], Osamu Matoba[4]; [1]*Graduate School of Science and Technology, Kyoto Inst. of Technology, Japan;* [2]*Advanced Technology Ctr., Kyoto Inst. of Technology, Japan;* [3]*Kubota Holography Lab. Corp., Japan;* [4]*Graduate School of System Informatics, Kobe Univ., Japan.* Thanks to parallel phase-shifting digital holography, we succeeded in 262500-frames-per-second phase-shifting digital holography. Dynamic phase change of air caused by focusing of a femtosecond light pulse was observed by the technique.

DWC26
Adiabatic Light Passage in Optical Waveguides Using Computer-Generated Planar Holograms, Ming-Chan Wu[1], Fu-Chen Hsiao[1], Shuo-Yen Tseng[1,2]; [1]*Dept. of Electro-Optical Engineering, National Cheng Kung Univ., Taiwan;* [2]*Advanced Optoelectronics Technology Center, Natl. Cheng Kung Univ., Taiwan.* We describe adiabatic light passage schemes using computer-generated planar holograms (CGPHs). The CGPHs are designed to mimic laser excitations used in population transfer of quantum states. Adiabatic mode converters are numerically investigated.

DWC27
Compressive Holographic Inversion of Particle Scattering, Lei Tian[1], Justin W. Lee[1], George Barbastathis[1,2]; [1]*Mechanical Engineering, MIT, USA;* [2]*Singapore-MIT Alliance for Res. and Technology (SMART) Ctr., Singapore.* Compressive sensing are applied to solve the holographic inverse source problem in the case of particle scattering. Both numerical simulations and experiments show good inversion results when the proposed method is applied.

DWC28
Hybrid CGH by Digitized Holography:CGH for Mixed 3-D Scene of Virtual and Real Objects, Yasuaki Arima[1], Kyoji Matsushima[1], Sumio Nakahara[2]; [1]*Electrical and Electronic Engineering, Kansai Univ., Japan;* [2]*Mechanical Engineering, Kansai Univ., Japan.* A hybrid CGH reconstructing 3-D scenes including virtual and real objects is created. The large-scaled wave-field of a real-existent object is captured by synthetic aperture digital holography and mixed with the virtual 3-D scene.

DWC29
A Novel Method for Rendering Specular and Smooth Surfaces in Polygon-Based High-Definition CGH, Hirohito Nishi[1], Kyoji Matsushima[1], Sumio Nakahara[2]; [1]*Electrical and Electronic Engineering Dept, Kansai Univ., Japan;* [2]*Mechanical Engineering Dept., Kansai Univ., Japan.* A new rendering method is proposed for smooth shading of specular surfaces in the polygon-based CGH. In the method, surface functions are divided into rectangular segments and the spectral envelopes are modified so as to produce specular reflection.

DWC30
Phase Shifting Approach for Indirect Synthetic Digital Holography, Nobukazu Yoshikawa[1], Kohei Machida[1], Keisuke Sanada[1]; [1]*Graduate School of Science and Engineering, Saitama Univ., Japan.* We propose an arbitrary phase shifting method for indirect synthetic digital holography. Experimental results show that a conjugate image is suppressed sufficiently if the phase shift amount is roughly set within the effective range.

DWC • Poster Session II-Continued
Wednesday, May 11, 2011
13:15–14:30

DWC31
Digital Holographic Surface Plasmon Resonance Microscopy, Jingang Zhong[1], Cuiying Hu[1], Shiping Li[1], Jiawen Weng[1]; [1]*Dept. of Optoelectronic Engineering, Jinan Univ., China.* Digital holography is applied to obtain the intensity and phase distributions of light wave in SPR. The refractive index distributions of sample near the substrate can be uniquely determined.

DWC32
Realistic Treatment of Spatial Light Modulator Pixelation in Real-Time Design Algorithms for Holographic Spot Generation, Martin Persson[1], David Engström[1], Jörgen Bengtsson[2], Mattias Goksör[1]; [1]*Physics, Univ. of Gothenburg, Sweden;* [2]*Microtechnology and Nanoscience, Chalmers Univ. of Technology, Sweden.* We have developed a method for compensation of crosstalk between adjacent pixels in liquid crystal based spatial light modulators. The method decreases uniformity errors of spot intensities in the farfield.

DWC33
Generating Function Approach for the Synthesis of Multichannel Spatial Filters by Diffractive Optics, Michael A. Golub[1], Shoam Shwartz[1], Shlomo Ruschin[1]; [1]*Electrical Engineering and Physical Electronics, Tel Aviv Univ., Israel.* Generating functions of orthogonal polynomials were exploited to design optical complex spatial filters for multichannel coherent correlator.

DWC34
Achieving the Rayleigh Limit in Fresnel Incoherent Correlation Holographic 3-D Fluorescence Microscopy, Gary Brooker[1], Nisan Siegel[1], Victor Wang[1], Joseph Rosen[2,1]; [1]*Biomedical Engineering, Johns Hopkins Univ., USA;* [2]*Electrical and Computer Engineering, Ben Gurion Univ. of the Negev, Israel.* Fresnel Incoherent Correlation Holography (FINCH) enables 3-D images to be created from incoherent light with just a camera and spatial light modulator. High resolution fluorescence microscopy at the Rayleigh optical limit will be demonstrated.

DWC35
Three-Dimensional Nanorod Tracking with Holographic Video Microscopy, Fook Chiong Cheong[1], David G. Grier[1]; [1]*Physics, New York Univ., USA.* We use holographic video microscopy to track the three-dimensional translational and rotational diffusion of copper oxide nanorods suspended in water. Analyzing a video sequence yields measurements of the freely diffusing nanorod's dynamics.

DWC36
Application of Digital Holographic Three-Dimensional Imaging Spectrometry to a Spatially Incoherent, Polychromatic Object, Sirawit Teeranutranont[1], Kyu Yoshimori[1]; [1]*Electrical Engineering and Computer Science, Iwate Univ., Japan.* A fully interferometric method to obtain spectral components of 3-D images has been applied to a polychromatic object composed of planar light sources, located at different positions, having different continuous spectra and shapes.

DWC37
Digital Holographic Adaptive Optics for Retinal Imaging, Changgeng Liu[1], Myung K. Kim[1], Xiao Yu[1], David C. Clark[1]; [1]*Dept. of Physics, Univ. of South Florida, USA.* A new adaptive optics retinal imaging system is presented that is based on the principles of digital holography and dispenses with the wavefront sensor and wavefront corrective element of the conventional adaptive optics system.

DWC38
Fully Inteferometric Three-Dimensional Imaging Spectrometry Using Hyperbolic-Type Volume Interferogram, Tetsuya Hashimoto[1], Kyu Yoshimori[1]; [1]*Electrical Engineering and Computer Science, Iwate Univ., Japan.* New fully interferometric method for three-dimensional imaging spectrometry using a hyperbolic-type volume interferogram has been proposed. This paper presents an experimental demonstration to validate the method.

DWD • 3-D Imaging and Microscopy
Wednesday, May 11, 2011
14:30–16:15
Myung K. Kim, Univ. of South Florida, USA, Presider

DWD1 • 14:30 Invited
BioPhotonics Workstation: 3-D Interactive Manipulation, Observation and Characterization, Jesper Gluckstad[1]; [1]*Technical Univ. of Denmark, Denmark.* In ppo.dk we have invented the BioPhotonics Workstation to be applied in 3-D research on regulated microbial cell growth including their underlying physiological mechanisms, *in vivo* characterization of cell constituents and manufacturing of nanostructures and new materials

DWD2 • 15:00
Holographic Reconstruction Using Intensity Interferometry, Dinesh N. Naik[1], Rakesh Kumar Singh[1], Takahiro Ezawa[1], Yoko Miyamoto[1], Mitsuo Takeda[1]; [1]*Department of Information and Communication Engineering, Univ. of Electro-Communications, Japan.*We propose and experimentally demonstrate reconstruction of a 3-D object encoded in a hologram using intensity interferometry based 4th order correlation of stochastic optical field.

DWD3 • 15:30
Quantitative Phase-Contrast Analysis and Visualization Improvement of Cells by Digital Holography, Lisa Miccio[1], Andrea Finizio[1], Melania Paturzo[1], Pasquale Memmolo[1], Francesco Merola[1], Giuseppe Coppola[2], Giuseppe Di Caprio[2], Mariano Gioffrè[2], Roberto Puglisi[3], Donatella Balduzzi[3], Roberto Puglisi[3], Pietro Ferraro[1]; [1]*CNR, Istituto Nazionale di Ottica del CNR, Italy;* [2]*CNR, Istituto per la Microelettronica e Microsistemi, Italy;* [3]*Istituto Sperimentale Italiano "Lazzaro Spallanzani", Italy.* Investigation of biological samples by Digital Holographic (DH) is conducted with the aim to perform quantitative analysis and improved visualization of biological cells. Experimental results for analysis in microfluidic channels are reported.

DWD4 • 15:45
Dynamic Cellular Volume Measurements by Single and Dual-Wavelength Digital Holographic Microscopy, Alexander Khmaladze[1], Rebecca Matz[1], Joshua Jasensky[1], Tamir Epstein[1], Chi Zhang[1], Mark Banaszak Holl[1], Zhan Chen[1]; [1]*Univ. of Michigan, USA.* We present a study of cellular volume measurements during staurosporine induced apoptosis. Small and large populations of cells were monitored for several hours using single- and dual-wavelength digital holography and volume decrease was observed.

DWD5 • 16:00
Second Harmonic Generation Holographic Microscopy in Biological Tissue Slices, Randy Bartels[1]; [1]*Biomedical Engineering, Colorado State Univ., USA.* Three-dimensional images of biological samples using nonlinear optical, holographic microscopy. The femtosecond oscillator operates at a wavelength with low scattering in the sample and its low average power prevents damage to the samples.

Coffee and Tea Break, *Convention Hall Foyer*
16:15-16:45

DWE • Advanced Imaging and Tomography
Wednesday, May 11, 2011
16:45–18:30
Toyohiko Yatagai, Utsunomiya Univ., Japan, Presider

DWE1 • 16:45 Invited
Digital Holography in Nonlinear Imaging
Alexandre Goy[1], Demetri Psaltis[1], Chia-Lung Hsieh[1], Ye Pu[1]; [1]*Ecole Polytechnique Federale deLausanne, Switzerland.*
Abstract (35 Word Limit): We discuss how digital holography applies to nonlinear imaging, including situations in which the object (e.g. second harmonic radiating imaging probes) or the medium is nonlinear (e.g. Kerr medium).

DWE2 • 17:15 Invited
Fractional Optics for Image Processing and Measurement, Guohai Situ[1], Laura Waller[1], Nicolas Pegard[1], Jason W. Fleischer[1]; [1]*Princeton Univ., USA.* Fractional optics involves the study of optical phenomena with fractional orders, for example, fractional Fourier transforms and fractional vortices. We review our work on the applications of fractional optics in image processing and measurement.

DWE3 • 17:45
Digital Holographic Tomography for 3-D Visualization, Georges Nehmetallah[1], Partha P. Banerjee[1], Sarat Praharaj[2]; [1]*EOP, Univ. of Dayton, USA;* [2]*DMS Tech. Inc., USA.* Using a novel single-beam holographic tomography based technique we are able to record holograms of translucent objects such as water droplets, and reconstruct the 3-D shapes using Radon transform

DWE4 • 18:00
Tomographic Imaging of a Digital Holographic Microscope, Yu-Chih Lin[1], Chau-Jern Cheng[1], Ting-Chung Poon[2]; [1]*Inst. of Electro-Optical Science and Technology, National Taiwan Normal Univ., Taiwan;* [2]*Bradley Dept. of Electrical and Computer Engineering, Virginia Tech, USA.*We report a novel tomographic imaging technique in digital holographic microscopy. Tomographic data are obtained by beam scanning instead of a rotating specimen approach. Preliminary experiments and simulation results are presented and discussed.

DWE5 • 18:15
PSF of 3-D pupils: Diffraction Tomography Formulation, Se Baek Oh[1], Yuan Luo[1], George Barbastathis[1,2]; [1]*Mechanical Eng., MIT, USA;* [2]*Singapore-MIT Alliance for Res. and Technology (SMART) Ctr., Singapore.* We analyze PSF of 3D pupils based on diffraction tomography formulation. The PSF exhibit strong shift variance. The output field is a coherent sum of rotated Ewald spheres weighted by decomposed incident plane waves.

PDP Session and Closing Remarks
Wednesday, May 11, 2011
18:30–19:30
George Barbastathis; MIT, USA, Presider
Toyohiko Yatagai, Utsunomiya Univ., Japan, Presider

DH Editors Dinner, *Offsite*
19:30-21:00

Key to Authors and Presiders

(**Bold** denotes Presider or Presenting Author)

T

U

V

W

X

Y

Z

Digital Holography and Three-Dimensional Imaging (DH) Meeting
Update Sheet and Exhibit Information

Withdrawn Presentations

DMC2	DWC26
DTuC24	DWC35
DTuE3	DWD5
DWB4	DWE4
DWC7	DWF5

Presenter Changes

Heather I.C. Dalgarno; *Univ. of St. Andrews, UK* will present **DWB1, Optimal focusing *in situ*: New Routes for Optical Trapping and Biophotonics.**

Hidenobu Arimoto; *Photonics Research Inst., Japan* will present **DTuC39, Measurement of Light-induced Refractive Index Change in Photopolymer with Quantitative Phase Microscopy**.

Nicholas Pavillon and Yann Cotte; *EPFL, Switzerland* will present **DWC16, Holographic Second Harmonic Generation Imaging.**

Presentation Schedule Updates

DWE1, Digital Holography in Nonlinear Imaging, Demetri Psaltis, *EPFL, Switzerland* will be presented in the **DMC2** time slot on Monday, 9 May at 16:30.

Program Updates

Please note the title and abstract update for presentation **DMC1, 3-D Capture, Processing, Display, and Perception with Digital Holography: Results from a European-Funded Project**, Thomas Naughton; *Univ. Oulu, Finland.* The European-funded project "Real 3D" brings together nine participants from academia and industry and continues a long-term effort to facilitate the greater presence of digital holography in the three-dimensional capture and display markets.

Please note the title and abstract update for presentation **DTuA2, Multi-Projector Autostereoscopic Displays,** Chao-Hsu Tsai, *ITRI, China.* Glasses-type 3-D cinemas ignite the requirement of consumers for glasses 3-D TV. It is possible that autostereoscopic displays may follow a similar path. Multi-projector autostereoscopic display systems provide a feasible solution for glasses-free 3D cinemas. This paper reviews, discusses, and compares various types of autostereoscopic display systems and introduces some research results in the world.

Program Corrections

Please note the corrected author block of presentation **DMC1, *Thomas J. Naughton*[8,1]**, *Claas Falldorf[2], Levent Onural[3], Pietro Ferraro[4], Christian Depeursinge[5], Sven Krueger[6], Yves Emery[7], Bryan M. Hennelly[8], and Małgorzata Kujawinska[9] [1]Oulu Southern Institute, University of Oulu, 84100 Ylivieska, Finland. Email: firstname.lastname@oulu.fi [2]BIAS – Bremer Institut f¨ur Angewandte Strahltechnik Gmbh, Bremen, Germany [3]Electrical and Electronics Engineering Department, Bilkent University, Ankara, Turkey [4]Istituto Nazionale di Ottica Applicata, Consiglio Nazionale delle Ricerche, Napoli, Italy [5]Advanced Photonics Laboratory, Ecole Polytechnique F´ed´erale de Lausanne, Switzerland ´ [6]HOLOEYE Photonics AG, 12489 Berlin, Germany [7]Lync´ee Tec Inc, 1015 Lausanne, Switzerland [8]Department of Computer Science, National University of Ireland Maynooth, Ireland [9]Faculty of Mechatronics/Institute of Micromechanics and Photonics, Warsaw University of Technology, Poland*

Presider Updates

Toyohiko Yatagai, *Utsunomiya Univ., Japan* will preside over the session, **DWB - Digital Holography in Metrology and Manipulation**.

Exhibitor Information

Hamamatsu Photonics K.K.
1126-1, Ichino-cho, Higashi-ku
Hamamatsu City, Shizuoka Pref., 435-8558, Japan
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Postdeadline programs are available at the registration desk.

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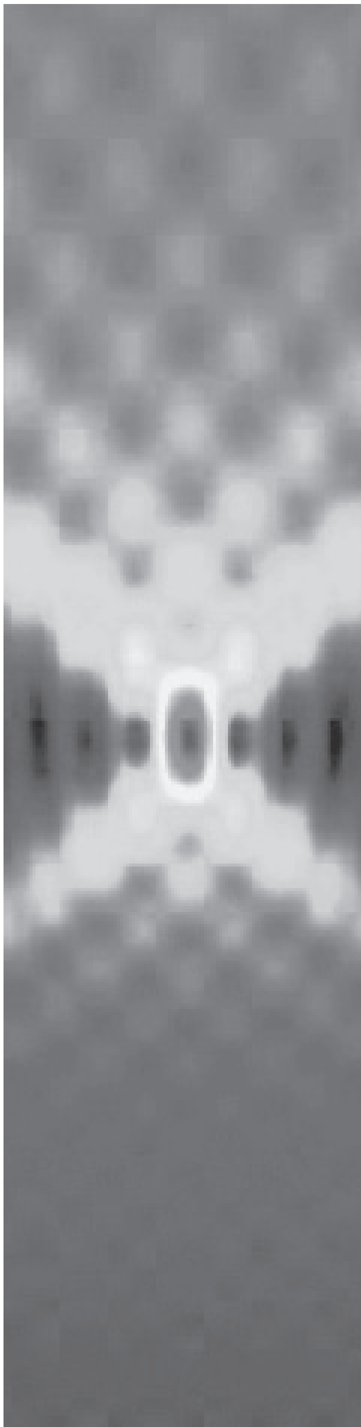

POSTDEADLINE PAPERS

Digital Holography and Three-Dimensional Imaging (DH)

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Digital Holography and Three Dimensional Imaging (DH) Postdeadline Paper Abstracts

• Wednesday, May 11, 2011 •

DWF • DH Postdeadline Session

Convention Hall (An-202)
18:30 –19:30
George Barbastathis, MIT, USA, Presider

DWF1 • 18:30
Image type full-color computer-generated hologram, *Yamaguchi Takeshi[1], Tadashi Miyahara[1], Yoshikawa Hiroshi[1]; [1]Electronics and Computer Science, Nihon Univ., Japan.* We have investigated the image type full-color computer-generated hologram that has full parallax and can be reconstructed with three color LEDs. The optical reconstructed image from the printed hologram is evaluated.

DWF2 • 18:40
Observation of moving picture of femtosecond light pulse propagation magnified by microscope objective, *Seiji Yamamoto[1], Takashi Kakue[1], Tetsuya Takimoto[1], Tatsuki Tahara[1], Yasuhiro Awatsuji[1], Shogo Ura[1], Kenzo Nishio[2], Toshihiro Kubota[3]; [1]Graduate school of Science and Technology, Kyoto Institute of Technology, Japan; [2]Advanced Technology Center, Kyoto Institute of Technology, Japan; [3]Kubota Holography Laboratory, Corporation, Japan.* We succeeded in observation of the 3.2-fold-magnified propagating light pulse whose duration was ~92 fs by using light-in-flight recording by holographic microscope that employs a magnifying optical system using a microscope objective.

DWF3 • 18:50
3D imaging based on full analytical Fraunhofer CGH, *Yuan-Zhi Liu[1], Jian-Wen Dong[1], Yi-Ying Pu[1], Bing-Chu Chen[1], He-Xiang He[1], He-Zhou Wang[1], Huadong Zheng[2], Yingjie Yu[2]; [1]State Key Lab of Optoelectronic Materials and Technologies, Sun Yat-sen Univ., China; [2]Dept. of Precision Mechanical Engineering, Shanghai Univ., China.* Fraunhofer-CGH proves to be valid in Fresnel region for display and have the same performance as Fresnel-CGH. An analytical Fraunhofer method is proposed for holographic computation of 3D triangle-mesh-model. Experiment reveals high quality results.

DWF4 • 19:00
Evaluation of holographic optical tweezers based on a hybrid diffractive system for manipulating microdroplets, *Yuki Kazayama[1], Takahiro Nishimura[1], Yusuke Ogura[1], Jun Tanida[1]; [1]Osaka Univ., Japan.* We applied a hybrid diffractive system to holographic optical tweezers and evaluated its performance for manipulating microdroplets. Experimental results demonstrate that microdroplets are transported successfully in parallel with equivalent velocities over the entire manipulation area.

DWF5 • 19:10
Fundamental Study on Hybrid Orthogonal-Phase Coding and Spatial Multiplexing for Holographic Data Storage, *Wei Song[1], Shiquan Tao[1]; [1]Beijing Univ. of Technology, China.* Calculation of the Fourier spectrum of the orthogonal phase-coded beam shows that in order to maintain phase-only modulation and orthogonality in the reference beam pattern, the phase modulator should be imaged to the recording plane.

DWF6 • 19:20
Cross-sectional Imaging of Paper Sheet by Common-path Swept Source Optical Coherence Tomography, *Kazuo Fujiwara[1,2], Osamu Matoba[2]; [1]Res. and Development Ctr., Glory Ltd., Japan; [2]Dept. of Systems Science, Graduate School of System Informatics, Kobe Univ., Japan.* A common-path swept source optical coherence tomography (SS-OCT) is a promising method for a stable cross-sectional imaging of high-speed translating samples. We demonstrate a cross-sectional imaging of paper sheets by a common-path SS-OCT system.

Image type full-color computer-generated hologram

Takeshi Yamaguchi, Tadashi Miyahara and Hiroshi Yoshikawa
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yamaguchi@ecs.cst.nihon-u.ac.jp

Abstract: We have investigated the image type full-color computer-generated hologram that has full parallax and can be reconstructed with three color LEDs. The object of the hologram is processed from 3D computer graphics polygon data and has shaded surface with hidden surface removal. The optical reconstructed image from the printed hologram is evaluated.

OCIS codes: 090.0090, 090.1760.

1. Introduction

The hologram has all three-dimensional information such as the binocular parallax, the convergence, the accommodation and so on. Therefore, the reconstructed image of the hologram provides the natural spatial effect. In particular, the viewer gets strong dimensional impression when the image is popping up from the hologram plane.

We have been studying the computer-generated image hologram (CGIH), whose interference fringe are calculate on the computer. First, we have shown that the virtual window can help the efficient calculation in the real-time holographic display [1]. Second, by using the developed hidden surface removal method, the reconstructed image of the high resolution CGIH does not show the overlap and the appearance of the occlusion holes [2].

In this paper, we have investigated the the full-color CGIH. For the color reproduction, we designed and made the optical setup. As the result, we have obtained a good full-color reconstructed image which has the full parallax.

2. Computer-generated image hologram

2.1. Optical image hologram

Since the object points of the image hologram are located very close or even on the hologram, the chromatic aberration caused by the difference of wavelength becomes small. Therefore, the hologram can reconstruct the image with white light. However, since the image blur increases when the distance from the hologram plane increases, it is difficult to reconstruct the image with large depth by white light. Since the diffracted angles vary with wavelength, the reconstructed image sometimes shows color changes. It can be observed when the viewer moves up and down, especially if the size of the image is large. However, this problem can be solved by using a laser or LED as an illumination source. By using a laser or LED whose spectral bandwidth is narrow, the blur of the reconstructed image due to the chromatic dispersion decreases.

2.2. Computation method

As a calculation method of the fringe pattern, we use the bipolar intensity [3,4] of Fresnel hologram. The hologram is located on the xy-plane, and the observer's side takes positive value of z-axis. The location of the i-th object point is specified as (x_i, y_i, z_i). Each point has real-valued amplitude a_i and relative phase ϕ_i. The intensity pattern of the interference of the object beam and reference beam is determined by

$$I_b(x,y) = \sum_{i=1}^{N} \frac{a_i}{r_i} \cos\{kr_i + \phi_R(x,y) + \phi_i\}, \tag{1}$$

where N is the number of the object point, ϕ_R is the phase of the reference beam. The wave number k is defined as $k = 2\pi/\lambda$, where λ is the free-space wavelength of the light. The oblique distance r_i between the i-th object point and the point (x,y) on the hologram is defined as

$$r_i = \sqrt{(x - x_i)^2 + (y - y_i)^2 + z_i^2}. \quad (2)$$

2.3. Virtual window

For the efficient calculation, CGIH employs a virtual window. By using the virtual window, the calculation area can be easily evaluated whether an area contributes to the reconstructed image. Also, for the proper hidden surface removal, the virtual window is divided to the small segments. Since the hologram plane and the camera plane are located at the different places, the calculation area is configured by each object data and the segmented virtual window [2].

3. Fringe printer

For printing CGH, we use the fringe printer [5] that consists of a laser, an *x–y* stage, and a liquid crystal on silicon (LCoS) as a spatial light modulator. A fractional part of the entire holographic fringe is displayed on the LCoS, and the demagnified image of it is recorded on a holographic plate. Then the plate is translated by the *x–y* stage to write the next part of the fringe. Therefore, the parameter of the output fringe pattern has a maximum of 200 x 200 mm^2 hologram size and 0.44 μm pixel pitch.

4. Optical reconstruction system

To reconstruct the image of the CGIH, we designed the optical setup. Figure 1 shows the drawing of the optical setup that consists of three LEDs, 2 dichroic mirrors and 3 hologram holders. Each reconstructed image are combined efficiently by the dichoroic mirrors.

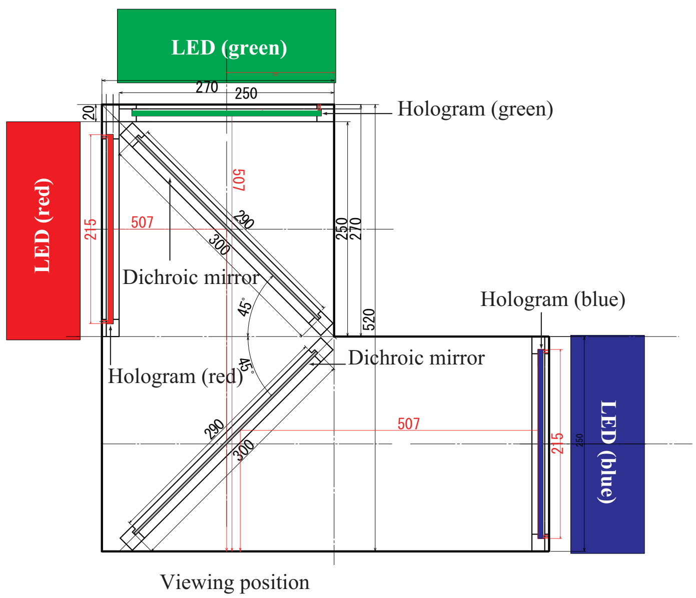

Fig. 1. Drawing of the optical setup for the reconstruction.

5. Result

5.1. Parameters of the CGIH

Table 1 shows the parameters of CGH made in this research. We use our fringe printer to record the fringe pattern. The total calculation time is approximately 60 hours with one PC (CPU: Intel Core(TM) i7 980X, 3.33 GHz. The printing time is about 30 hours.

5.2. Reconstructed images

Figure 2 shows the photograph of the reconstruction system. Figures 3 shows the reconstructed images of the CGIH and the perspective images of the object data used in this research. As a recording material, we used VRP-M manufactured

Table 1. Parameter of the hologram

Parameter of the hologram	Value
Resolution [pixel]	250,000 x 160,000
Size [mm^2]	110 x 70.4
Pitch [μm]	0.44
Wavelengths [nm]	660, 525, 470
Incident angle of reference beam [deg.]	20
Segment size [pixel]	1,920 x 1,080
Virtual window size [m]	1.15 x 0.31
Position of the virtual window [m]	(0, 0, 1.0)
Partition number of virtual window	31 x 21
Number of Object points (ave.)	20,000

by Slavich. The reconstructed images show the same color of the object data. The parallax of the reconstructed images are also confirmed when the observing point is changed.

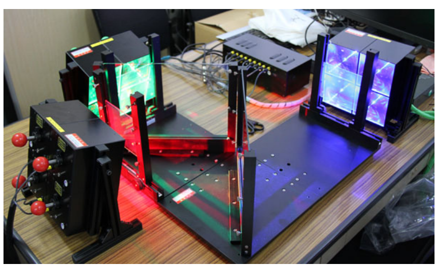

Fig. 2. Photograph of the reconstruction system.

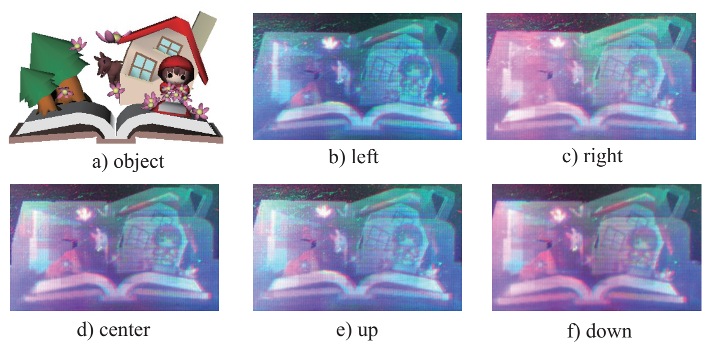

Fig. 3. Reconstructed image from various view points.

6. Conclusion

In this research, we have investigated the full-color CGIH. From the reconstructed image, one can confirm same colors of the object data are reproduced. However, since the diffraction efficiency of the printed CGH is not high enough, there are a lot of noises in the reconstructed image. We would realize the noise-reduction in the reconstructed image from the CGIH as the future work.

7. Acknowledgments

The authors thank the Futaba Electronics Memorial Foundation for the support of this project.

References

1. T. Yamaguchi, G. Okabe and H. Yoshikawa, “Real-time Image Plane Full-color and Full-parallax Holographic Video Display System,” Optical Engineering, **46**, 12, pp. 125801(1–8) (2007).
2. H. Yoshikawa, T. Yamaguchi and T. Miyahara, “Image type computer-generated hologram of shaded object,” 9th IEEE/ACIS International Conference on Computer and Information Science, pp.827–830 (2010).
3. Waters, J. P., “Holographic image synthesis utilizing theoretical method,” *Applied Physics Letters* **9**(11), 405–407 (1966).
4. Lucente, M., “Interactive computation of hologram using a look-up table,” *Journal of Electronic Imaging* **2**(1), 28–34 (1993).
5. H. Yoshikawa and T. Yamaguchi, “Computer-generated holograms for 3D display,” Chinese Optics Letters, **7**, 12, pp. 1079–1082 (2009).

Observation of moving picture of femtosecond light pulse propagation magnified by microscope objective

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Abstract: We succeeded in observation of the 3.2-fold-magnified propagating light pulse whose duration was ~92 fs by using light-in-flight recording by holographic microscope that employs a magnifying optical system using a microscope objective.
OCIS codes: (090.0090) Holography; (320.7160) Ultrafast technology; (320.2250) Femtosecond phenomena; (110.0180) Microscopy

1. Introduction

Recently, a femtosecond pulsed laser has been applied to many research fields such as natural sciences [1], materials processing [2], photonic networks [3], and so on. Among these fields, it is significant to observe the behavior of a femtosecond light pulse in order to fully elucidate the dynamics of ultrafast phenomena, the condition of effective materials processing, and the characteristics of optical devices used in photonic networks. As is well known, the speed of light is 300,000 km/s in air and the fastest in the world. Therefore, the propagation of light pulses cannot be captured even by using a high-speed camera.

Light-in-flight recording by holography (LIF holography) [4,5] is capable of observing light pulse propagation. This technique can observe a three-dimensional (3-D) image of light pulse propagation as a spatially and temporally continuous moving picture. The observation of several optical phenomena by using LIF holography has been reported [5,6]. In the previous reports, light pulse propagation in a macroscopic field of view was observed. However, ultrafast phenomena such as plasmas induced by a ultrashort pulsed laser occur in a microscopic field of view. Thus, it is beneficial to observe the behavior of the light pulse in a microscopic field of view. It has been numerically confirmed that LIF holography can observe magnified images of light pulse propagation [7]. However, experimental observation of magnified light pulse propagation has not been reported yet.

In this paper, we constructed a system for recording and observing a moving picture of light pulse propagation magnified by a microscope objective. This system combines LIF holography and an optical microscope, and is a 3-D microscope which is capable of observing magnified light pulse propagation. In addition, we experimentally demonstrate the observation of magnified light pulse propagation by using the constructed system, for the first time.

2. Light-in-flight recording by holography

Figure 1 shows the basic recording arrangement of LIF holography. In LIF holography, an ultrashort pulsed laser is used to record a hologram. A light pulse generated from the ultrashort pulsed laser is divided into two pulses by a beam splitter. Each pulse is collimated by a microscope objective and a collimator lens. One is a light pulse illuminating an object and the other is a reference light pulse. The light pulse illuminating the object and the reference light pulse are introduced into a diffuser plate and a holographic plate with an inclined angle, respectively. The light pulse scattered by the diffuser plate is an object light pulse. Interference fringes are formed only when both the object light pulse and the reference light pulse meet on the holographic plate. Since both the illuminating light pulse and the reference light pulse sweep over the diffuser plate and the holographic plate, respectively, the behavior of the light pulse propagating on the diffuser plate at each instant is recorded in different parts of the

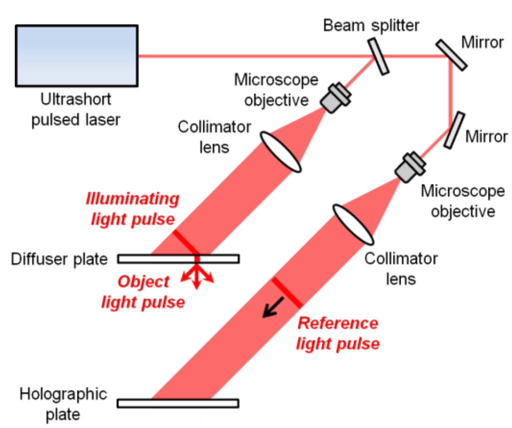

Fig. 1. Basic recording arrangement of LIF holography

holographic plate. The holographic plate on which the interference fringes are recorded changes into a hologram after chemically developing the holographic plate.

A continuous wave (CW) laser is used to reconstruct the image of the light pulse. When the collimated CW laser beam is introduced into the hologram, the images of the light pulse at each instant are reconstructed from each part of the hologram. We can obtain a spatially and temporally continuous moving picture of light pulse propagation when the gazed point on the hologram is moved along the same direction in which the cross section between the reference light pulse and the holographic plate propagated.

3. Principle of recording of magnified image

It is necessary to introduce the magnifying optical system into the recording arrangement of LIF holography in order to record and observe the behavior of the light pulse in a microscopic field of view. To obtain the magnified image in LIF holography the following conditions and contraptions were considered. In LIF holography, the light pulse scattered by the diffuser plate is the object light pulse and a diverging wave. Therefore, it is preferable that the object light pulse after passing the magnifying optical system is also the diverging wave. Then, we construct a system for observing the ultrashort light pulse propagation as a magnified virtual image. Meanwhile, if the magnification of the reconstructed image is different according to the depth position, the image is distorted and cannot be faithfully reconstructed. Then, we introduced the magnifying optical system that provides unit magnification at an arbitrary depth.

In consideration of the above-mentioned contraptions, the principle of the recording of the magnified image is schematically shown in Fig. 2. We introduced the magnifying optical system of an optical microscope into the recording arrangement of LIF holography. A microscope objective and a convex lens are arranged between the diffuser plate and the holographic plate. The object light pulse scattered by the diffuser plate was introduced into the holographic plate after passing the microscope objective and the convex lens in turn. The distance between the diffuser plate and the microscope objective L is longer than the focal length of the microscope objective f_{mo}. Furthermore, the distance between the microscope objective and the convex lens is equal to the sum of these focal lengths f_{mo} and f_{pl}. A magnified real image of the light pulse on the diffuser plate is formed before the convex lens by the microscope objective. A magnified virtual image of the real image is formed before the microscope objective by the convex lens. The virtual image of the magnified real image is the reconstructed image which is observed in the experiment.

The position where the reconstructed image appears depends on the distance between the diffuser plate and the microscope objective L. The magnification of the reconstructed image m is given as $m = -f_{pl}/f_{mo}$. A minus sign in the right side of the equation means that the inverted image is obtained as the reconstructed image. Therefore, the light pulse illuminating the object is obliquely introduced from the top left; meanwhile, the reference light pulse is obliquely introduced from the bottom left, as shown in Fig. 2.

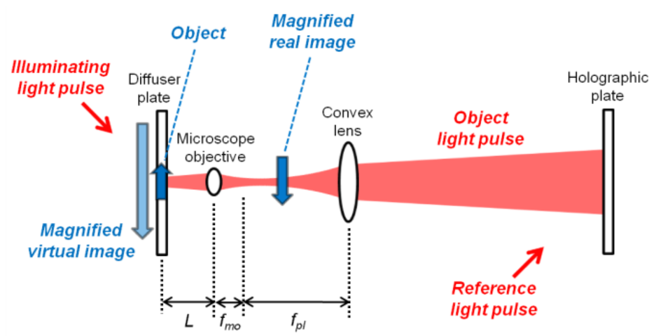

Fig. 2. Principle of the recording of the magnified image

4. Experiment

Figure 3 shows the schematic diagram of the optical setup of the experiment. We used a mode-locked Ti:sapphire laser (Solstice, Spectra-Physics Inc.) to generate a femtosecond light pulse whose center wavelength and duration were 800 nm and ~92 fs, respectively. A near-infrared light pulse generated from the laser was converted into a visible light pulse whose wavelength was 400 nm by second harmonic generation. This is because most of the commercially available holographic plates are sensitive to the visible light. The visible light pulse was introduced into the recording system which combined LIF holography and an optical microscope. We used a microscope objective and a convex lens whose focal lengths were 16.6 mm and 60.0 mm, respectively, to observe several-fold magnified moving picture of light pulse propagation. We set the distance between the diffuser plate and the microscope objective L to be 29.2 mm to form the reconstructed image on the position of the diffuser plate. We set the distance between the convex lens and the holographic plate to be 150 mm to introduce the collimated reference light pulse into the holographic plate. The object light pulse was magnified after passing the magnifying optical system. Therefore, the propagation speed of the object light pulse on the holographic plate is faster than that of the light pulse illuminating object on the diffuser plate. The difference between the propagation speed of the object light pulse and that of the reference light pulse on the holographic plate needs to be reduced in order to widen the area in which interference fringes are recorded. To meet the need, the light pulse illuminating the object and the reference light pulse were introduced into the diffuser plate and the holographic plate at 75° and 30° against the normal of each plate, respectively. We used Konica-P5600 as the holographic plate which was sensitive to blue and green lights. Also, we patterned the character on the diffuser plate to easily recognize the magnification of the light pulse.

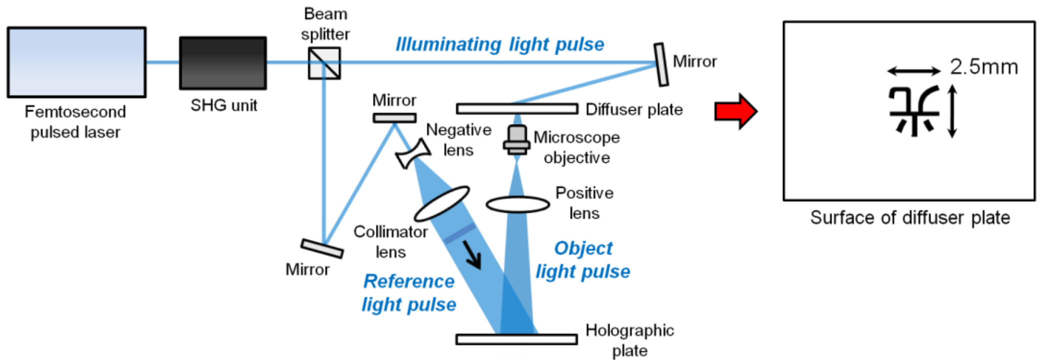

Fig. 3. Schematic diagram of the optical setup in the experiment

We used a diode-pumped solid state (DPSS) laser operated at 532 nm to reconstruct the hologram. Figures 4 (a)-(c) show three scenes extracted from the obtained moving picture. A bright green line is the reconstructed image of the magnified femtosecond light pulse. We can see that the light pulse propagates from left to right when the gazed point on the hologram is moved from left to right. The actual time of the observed phenomenon and the time interval between the adjacent scenes in Fig. 4 were 24.7 ps and 3.3 ps, respectively. Figures 4 (d)-(f) are the enlarged images of the light pulse shown in Figs. 4 (a)-(c), respectively. As shown in Figs. 4 (d)-(f), the character on the diffuser plate was inverted and magnified. The magnification was 3.2 fold in comparison with the size of the character which be patterned on the diffuser plate.

Because we used the microscope objective and the convex lens whose focal lengths were 16.6 mm and 60.0 mm, respectively, a 3.6-fold magnified image should be theoretically observed. The reason of the difference between the experiment result and the theoretical one is under review in detail.

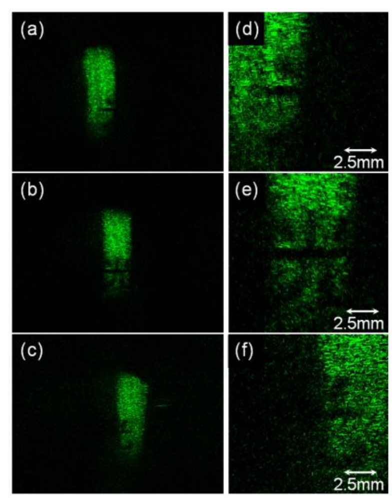

Fig. 4. Reconstructed images of the magnified light pulse. (a)-(c) Three scenes extracted from the obtained moving picture, (d)-(f) enlarged images of the light pulse shown in (a)-(c), respectively.

5. Conclusion

We succeeded in experimental observation of femtosecond light pulse propagation magnified by a microscope objective, for the first time. The magnification of the observed image was 3.2 fold. The higher-magnification of light pulse propagation will be possible by improving the magnifying optical system. It is expected that this study contributes to elucidate the dynamics of ultrafast phenomena and the condition of effective materials processing.

6. References

[1] M. Centurion, Y. Pu, Z. Liu, D. Psaltis, T. W. Hänsch, "Holographic recording of laser-induced plasma," Opt. Lett. **29**, 772-774 (2004).
[2] O. Matoba, Y. Kitamura, T. Manabe, K. Nitta, and W. Watanabe, "Fabrication of controlled volume scattering medium in poly (methyl methacrylate) by focused femtosecond laser pulses," Appl. Phys. Lett. **95**, 221114 (2009).
[3] O. Matoba, B. Javidi, "Secure Ultrafast Communication with Spatial-Temporal Converters," Appl. Opt. **39**, 2975-2981 (2000).
[4] N. Abramson, "Light-in-flight recording by holography," Opt. Lett. **3**, 121-123 (1978).
[5] T. Kubota, Y. Awatsuji, "Observation of light propagation by holography with a picoseconds pulsed laser," Opt. Lett. **27**, 815-817 (2002).
[6] T. Kubota, K. Komai, M. Yamagiwa, and Y. Awatsuji, "Moving picture recording and observation of three-dimensional image of femtosecond light pulse propagation," Opt. Express **15**, 14348-14354 (2007).
[7] T. Kakue, M. Makino, M. Aihara, A. Kuzuhara, Y. Awatsuji, K. Nishio, S. Ura, and T. Kubota, "Light-in-flight recording by holographic microscope and its numerical verification," Jpn. J. Appl. Phys. **48**, 09LD01-1-5 (2009).

3D imaging based on full analytical Fraunhofer CGH

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Abstract: Fraunhofer-CGH proves to be valid in Fresnel region for display and have the same performance as Fresnel-CGH. An analytical Fraunhofer method is proposed for holographic computation of 3D triangle-mesh-model. Experiment reveals high quality results.

OCIS codes: (090.0090) Holography; (090.1760) Computer holography; (090.2870) Holographic display

1. Introduction

In recent years, three dimensional (3D) displays have aroused people's tremendous interest. Since digital technology made great progress during the past decades, computer-generated hologram (CGH) used for 3D display has a great prospect, which can flexibly generate wavefronts of real existent or nonexistent object [1, 2]. For convenient observation, different depths of objects are usually designed to locate in the Fresnel region [3]. Hence, Fresnel diffraction are the most commonly used method in CGH for 3D display. For example, it has been widely used in planar layers method [4], 3D affine transformations method [5], phase-added stereogram [6], et al. On the other hand, Fraunhofer CGH (Fh-CGH) is usually considered could only be applied in the far-filed condition, which is like the optical Fraunhofer holography. And it is also thought that the reconstruction performance of Fh-CGH is just similar to Fourier CGH [3, 7].

In this research, we prove that Fraunhofer diffraction formulism can be applied in the Fresnel region for CGH calculation, even the far-field condition is not satisfied. Numerical and experimental reconstructions reveal that the performance of Fh-CGH is the same as Fresnel CGH (Fr-CGH), such as the large depth of field. The use of Fh-CGH can reduce the computational complexity and supply a versatile probability to improve the calculation of Fourier transform (FT). Based this statement, we derive an analytical theory for describing the diffraction of 3D surface objects, which consists of spatial triangle-meshes. Analytical diffuser and modified Lambert brightness are developed to improve the viewing angle and avoid unexpected shading. GPU is employed for parallel computation to dramatically decrease the calculation time, which performs hundreds of times faster than CPUs. Numerical and optical reconstruction is carried out to demonstrate the algorithm. The results reveal high quality 3D effect.

2. Theory and experiment

Assume a planar object in the Fresnel region is parallel to the hologram. If we use Fresnel and Fraunhofer diffraction formulism to encode two CGHs, i.e. Fr-CGH and Fh-CGH, and then use Fresnel diffraction for both CGHs to describe the physical reconstruction process, the formulas tell us that there is only an additional phase factor in the complex amplitude in the imaging plane between Fr-CGH and Fh-CGH, which are $\mathcal{O}_{virt}^{Fr}=\mathcal{O}_o(x',y')$ and $\mathcal{O}_{real}^{Fr}=\exp\{-j4\pi[(x'\cos\alpha-z\cos^2\alpha)+(y'\cos\beta-z\cos^2\beta)]/\lambda\}\,\mathcal{O}_o^*(x'-2z\cos\alpha,\ y'-2z\cos\beta)$ for Fr-CGH, while $\mathcal{O}_{virt}^{Fh}=\exp[-j\pi(x'^2+y'^2)/\lambda z]\ \mathcal{O}_o(x',\ y')$ and $\mathcal{O}_{real}^{Fh}=\exp[j\pi(x'^2+y'^2)/\lambda z]\ \mathcal{O}_o^*(x'-2z\cos\alpha,\ y'-2z\cos\beta)$ for Fh-CGH. However, for the purpose of display, people only concern intensity of the reconstructed virtual (real) image rather than the complex amplitude. Therefore, the reconstructed performances of these two CGHs are the same in 3D display. And we also find that the quadratic phase in Fraunhofer formula is the reason why Fh-CGH can reconstruct deep scenes, which makes itself different from Fourier CGH. Experiment is carried out to support the statement and results are indicated in Fig .1, where phase-only spatial light modulator (SLM; Holoeye Pluto, 1920*1080, pixel pitch $8\mu m*8\mu m$) is used to display hologram and the real images is captured by camera. No Fourier lens is needed. The performances of Fh-CGH (Figs.1(c), 1(e)) are consistent with Fr-CGH (Figs. 1(b), 1(d)), especially for focusing and defocus effects. It indicates Fh-CGH can maintain good performance as Fr-CGH, even for objects in the Fresnel region.

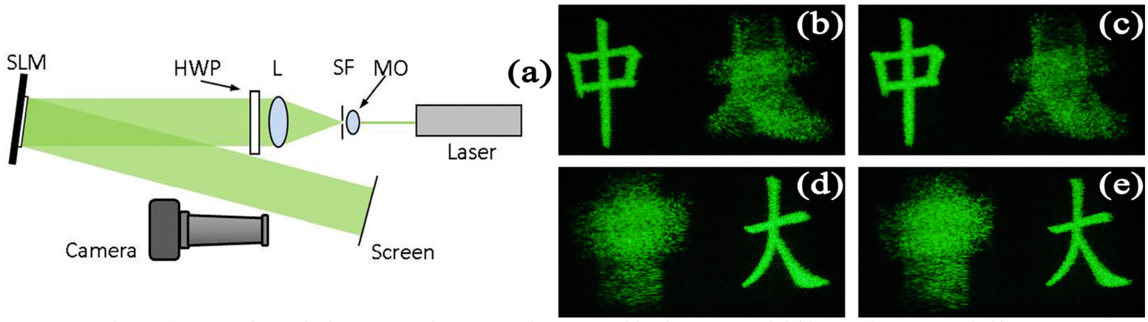

Fig. 1. (a) Set-up for optical reconstruction. MO: microscope objective, SF: spatial filter, L: lens, HWP: half-wave plates. Reconstruction in 800mm for (b) Fr-CGH and (c) Fh-CGH; in 1100mm for (d) Fr-CGH and (e) Fh-CGH.

For a slanted and non-axis planar object, we derive the diffraction distribution on the hologram plane through rotation transformation [1], which is similar in form to the Fresnel diffraction for parallel plane case above. Based on the above discussions, we can discard the quadratic phase within Fresnel integral and change it to the form that is similar to Fraunhofer diffraction. Therefore, the most important thing turns to how to calculate the FT of the slanted plane.

As in the usual computer graphics approach, we treat the 3D surface object as a combination of triangle patches (Fig. 2(a)). The superposition of diffraction field of triangle apertures is equal to the diffraction field of the 3D surface object (Fig. 2(b)). Applying affine transform operation, the FT of arbitrary triangles can be obtained through a fiducial triangle (Fig. 2(c) [1]. In order to smooth the Fourier spectrum, we proposed a triangle-tiling diffuser method. The fiducial triangle we used is tiled by small elemental right triangles, each of whom holds a different random phase. The Fourier spectrum of one elemental right triangle ("A" in Fig. 2(c)) can be analytically deduced [1], and then the Fourier spectrum of other elemental triangles (e.g. "B","C" in Fig. 2(c)) can be easily acquired by using the symmetry and linear-shifting properties of FT. After superposition, it is equivalent that the Fourier transform of a diffused fiducial triangle is analytically achieved. Modified Lambert brightness is also developed to avoid some artificial shading. These techniques supply an effective way to analytically compute a diffused 3D object. Hence, the CGH can be encoded as Kinoform, which has a high diffraction efficiency applied in phase-only SLM.

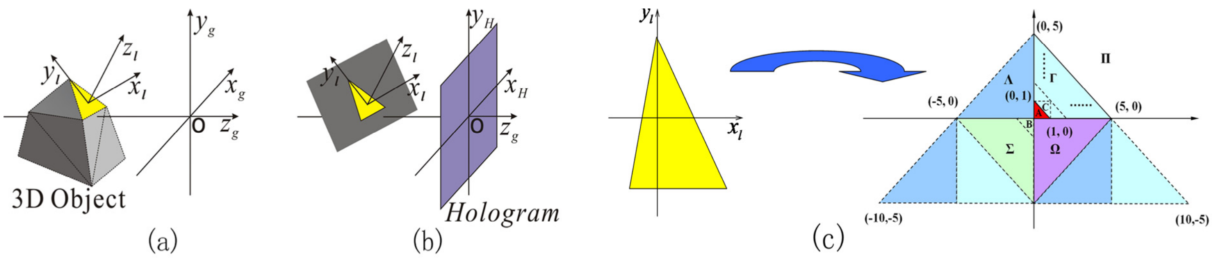

Fig. 2. (a) 3D surface Object composed by triangle patches. (b) Diffraction of triangle aperture. (c) Calculation of Fourier transform of arbitrary planer triangle using determinate fiducial triangle through affine transform.

Furthermore, the analytical approach allows us to generate the hologram directly pixel by pixel without discrete numerical algorithm, which may arouse numerical errors while undersampling. Such pixel independent calculation in the hologram plane is also very suitable for parallel computation. We implement the analytical approach as a parallel algorithm running on a commodity GPU. NVIDIA GPU chipset- GeForce GTX 285, and CUDA compile - a GPU programming environment are adopted. We find the GPU acceleration can run hundreds faster than CPU serial codes and CPU 8-cores parallel codes. While the number of triangle is about 100, it achieves a real time calculation rate. Therefore, we propose an inexpensive and high-efficiencies method for CGH computation of 3D objects.

To confirm the feasibility of such analytical method, a slanted triangle, whose orthogonal projection size is about 40mm by 22mm, is calculated and optical reconstructed. The front vertex is in 800mm from the hologram, and the rear right-angle edge lies in 1100mm. The far-field condition is not satisfied. The experimental set-up is the same as Fig. 1(a). Results are shown in Fig. 3 (a), (b). It can be seen that when we focus on the front part of the slanted triangle, the front vertex is very clear and the rear part is blurred (Fig. 3(a)). While the rear edge is focused, it becomes very sharp and the front vertex is vague (Fig. 3(b)). This experiment shows that our analytical method for slanted plane object works correctly.

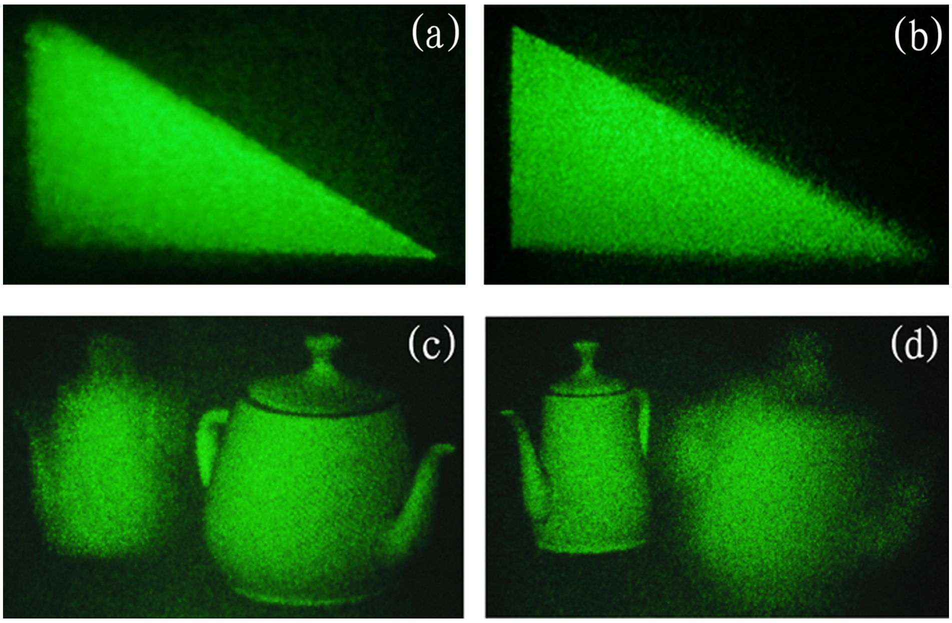

Fig. 3. Reconstructed of single slanted triangle in (a) 800mm, where front vertex is focused, and (b) 1100mm, where rear right-angle edge is focused.. Reconstructed of two teapots: (c) focusing on the front teapot in 800mm, and (d) focusing on the rear teapot in 1100mm

A 3D scene, consisting of two teapots with size of 40mm by 23mm, is also calculated and optical reconstructed, as shown in Fig. 3 (c) and (d). These two teapots are located at distances of 800mm and 1100mm from the hologram respectively, where the far-field condition is also not satisfied. It can be seen that the basic-triangle tiling diffuser of 3D object supplies a continuous and smooth surface, which performs a good solid effect. When the front fat teapot is focused (Fig.3(c)), it becomes clear and the rear slim teapot turns to vague, and vice versa (Fig. 3(d)). This defocus effect gives an impressive depth sensation and strong 3D feeling. The modified Lambert brightness technique adds to the vivid impression of surface curvature, which also enhances the 3D feeling.

3. Conclusion

Fraunhofer-CGH is demonstrated to be valid even in the Fresnel region. A high-speed full analytical algorithm for 3D objects is proposed. Both numerical and experimental results well demonstrated our algorithm. Our method may be a potential way to achieve a high quality, 3D holographic displays in real time.

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4. References

[1] Yuan-Zhi Liu, Jian-Wen Dong, Yi-Ying Pu, Bing-Chu Chen, He-Xiang He, and He-Zhou Wang, “High-speed full analytical holographic computations for true-life scenes,” Opt. Express **18**, 3345-3351 (2010).
[2] Yi-Ying Pu, Jian-Wen Dong, Bing-Chu Chen, Yuan-Zhi Liu, and He-Zhou Wang, "Three-dimensional imaging with monocular cues using holographic stereography", Opt. Lett. **35**, 3279-3281 (2010).
[3] S. A. Benton, V. M. Bove, Jr, Holographic Imaging (John Wiley and Sons, Inc., 2008)
[4] M. Bayraktar and M. Ozcan, “Method to calculate the far field of three-dimensional objects for computer-generated holography”, Appl. Opt. **49**, 4647-4654 (2010).
[5] H. Sakata and Y. Sakamoto, “Fast computation method for a Fresnel hologram using three-dimensional affine transformations in real space”, Appl. Opt. **48**, H212-H221 (2009).
[6] H. Kang, T. Yamaguchi, and H. Yoshikawa, “Accurate phase-added stereogram to improve the coherent stereogram”, Appl. Opt. **47**, D44-D54 (2008)
[7] B. R. Brown and A. W. Lohmann, “Complex Spatial Filtering with Binary Masks”, Appl. Opt. **5**, 967-969 (1966).

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Evaluation of holographic optical tweezers based on a hybrid diffractive system for manipulating microdroplets

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Abstract: We applied a hybrid diffractive system to holographic optical tweezers and evaluated its performance for manipulating microdroplets. Experimental results demonstrate that microdroplets are transported successfully in parallel with equivalent velocities over the entire manipulation area.

OCIS codes: 350.4855, 070.6120, 050.1970, 090.2890.

1. Introduction

Holographic optical tweezers are a useful manipulation tool based on flexibility of computer generated holograms (CGHs) in generating optical patterns. They enables dynamic and parallel manipulation of objects by real-time generation of optical patterns [1]. The capability of the method in manipulating objects whose refractive index is lower than that of surrounding medium is attractive [2]. A microdroplet in oil-solvent is a good example of low-index objects to be manipulated by holographic optical tweezers. Microdroplets are useful as microscale reacting volumes that contain a small amount of molecules.

We are studying about a controlling method of DNA reactions by holographic optical manipulation of microdroplets. A reaction is controlled by fusing multiple microdroplets that contain different DNA solutions. For example, logic operations using DNA as input and light as output in microdroplets can be executed by the method [3]. Holographic optical tweezers enables to reconfigure a procedure of DNA logic operations on demand.

To realize massively parallel processing of DNA reactions, large-area manipulation is necessary . In addition, it is required to achieve uniform performance over the entire area of manipulation. To meet the demand, generation of optical patterns is important, and a hybrid diffractive system, which consists of multiple diffractive devices, is a promising system configuration [4]. In this study, we evaluate performance of holographic optical tweezers based on a hybrid diffractive system for manipulating microdroplets. Uniform manipulation performance over a large area is demonstrated by measuring transportation velocity of microdroplets on central and peripheral areas of the field of view of the microscope used.

2. Holographic optical tweezers based on a hybrid diffractive system

In a hybrid diffractive system, multiple diffractive devices are used cooperatively to generate desired optical patterns. Division of roles between the diffractive devices offers expansion of functionality in optical pattern generation or reduction of design cost. As an example, a combination of a static CGH and a spatial light modulator (SLM) is usable to produce a dynamic local pattern and duplicate it over a large area for parallel manipulation of many microdroplets.

Figure 1 shows a primal configuration of the system. The SLM plane is imaged on the static CGH plane, and optical field just after the CGH is Fourier transformed through the objective lens. As a result, the convolution pattern between an optical pattern generated using the SLM alone and that using the CGH alone is created on the output plane (the focal plane of the objective lens). For example, it is possible to implement the same manipulation designated by the SLM at multiple positions of light spots created by the CGH simultaneously.

3. Experiments

A microdroplet in an oil solvent receives repulsive force from light, so that stable manipulation of the microdroplet using a single focused light spot is impossible. Arranging multiple light spots around the microdroplet is a reasonable

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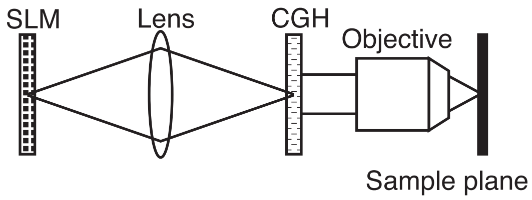

Fig. 1. A primal configuration of a hybrid diffractive system.

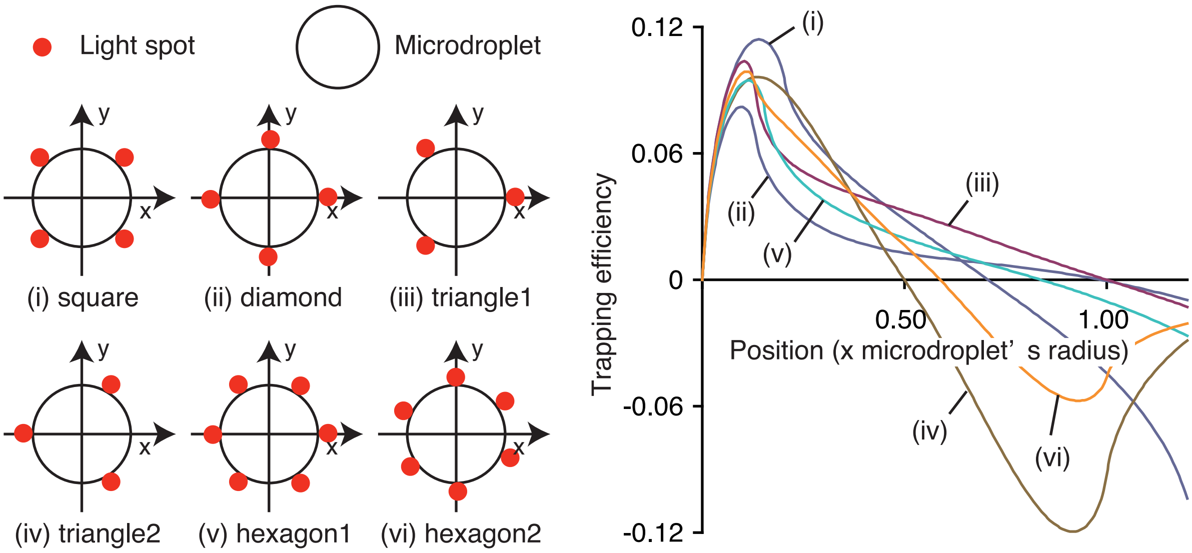

Fig. 2. The considered optical patterns consisting of multiple spots (left) and dependence of trapping efficiency on relative position (right).

method to manipulate it intentionally. To investigate usable arrangement, we considered 6 optical patterns and calculated trapping efficiency based on a ray-optics model. Trapping efficiencies when transporting in x direction for the individual optical patterns are shown in Fig. 2. The horizontal axis is the relative position, which is normalized by the radius of the microdroplet, of the optical pattern from the center of the microdroplet. The rectangle pattern provides the highest trapping efficiency and induces restoring force within relatively large range of the position. Based on the result, the rectangle pattern is used in experiments.

The experimental system is shown in Fig. 3. A semiconductor laser (wavelength: 660 nm, output: 130 mW) is used as a light source. The optical field modulated by the SLM (Hamamatsu Photonics K.K., LCOS-SLM X10468-01) is imaged on the CGH plane with magnification of 2/5. The optical field just after the CGH is imaged on the back focal plane of the objective lens 1, and desired patterns is generated on the sample plane. A 80-lp/mm grating (Edmund Optics, 46070-K) which is specially designed to produce the 0th and $\pm$ 1st orders of light with equivalent power was used as a CGH. In this setup, the optical pattern generated using the SLM alone is duplicated at a 48-μm period. Microdroplets were prepared by mixing distilled water, acetophenone as solvent, and sorbitan monooleate as surfactant. The microdroplet layer was extracted from the mixture and it was sandwiched between cover slips.

To evaluate relationship between optical power and transportation velocity, the transportation velocity of a microdroplet was measured using the rectangle pattern generated by the SLM alone. The spacing between the spots was 4.0 μm. A microdroplet of about 4 μm in diameter was transported from 8.7 μm above the origin to 8.7 μm below the origin. The optical patterns were shifted in 0.45 μm steps. Dependence of the maximum transport velocity on the total illumination power is shown in Fig. 4. By linear approximation, the relationship between transportation velocity $v(\mu\text{m}/\text{sec})$ and necessary optical power $P(\text{mW})$ when using the rectangle pattern is determined as $v = 0.33P - 0.31$.

The next experiment was performed using the hybrid diffractive system of the SLM and CGH. Sequential images during simultaneous transportation of three microdroplets is shown in Fig. 5. The microdroplets were manipulated at the individual positions of the spots generated by the CGH. It can be seen that the three microdroplets are transported

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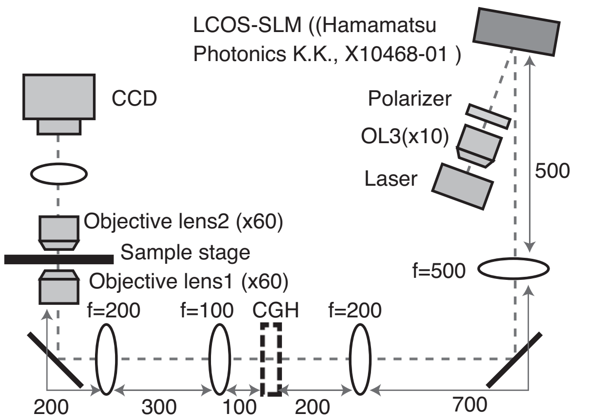

Fig. 3. The experimental setup.

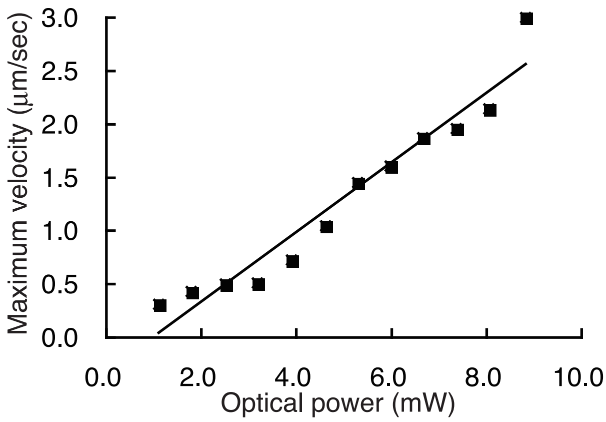

Fig. 4. Relationship between the maximum transport velocity and total illumination power.

with the same manner in responding to the sequential change of modulation by the SLM.

The maximum transportation velocity was measured at the 0th and the ±1st positions; the velocities were 0.55 μm/s (0th), 0.53 μm/s (+1st), and 0.56 μm/s (-1st). Approximately equivalent transportation velocities were obtained at 48 μm distant from the optical axis. We succeeded in achieving uniform performance over the entire manipulation area using the hybrid diffractive system.

4. Conclusions

We applied a hybrid diffractive system to holographic optical tweezers for manipulating microdroplets. The numerical calculation shows that the rectangle pattern is a good selection to obtain a high velocity using multiple spots. The experimental results demonstrated that microdroplets were successfully transported at the central and peripheral areas of the field of view of the microscope and the equivalent performance was achieved over the entire manipulation area. The method is usable for parallel manipulation within a large area, and it can be applied to on-chip reconfigurable DNA operations using microdroplets.

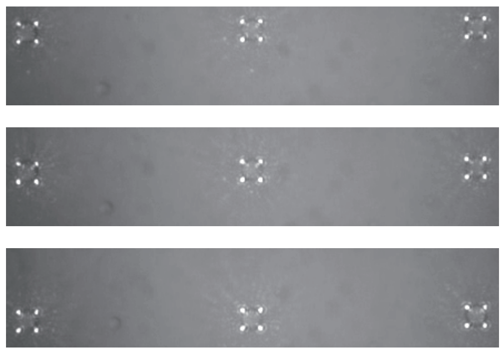

Fig. 5. Simultaneous transportation of three microdroplets at three positions.

References

1. J. E. Curtis, B. A. Koss, D. G. Grier, "Dynamic holographic optical tweezers," Opt. Commun. **207**, 169–175 (2002).
2. P. Prentice, M. MacDonald, T. Frank, A. Cuschier, G. Spalding, W. Sibbett, P. Campbell, and K. Dholakia, "Manipulation and filtration of low index particles with holographic Laguerre-Gaussian optical trap arrays," Opt. Express **12**, 593–600 (2004).
3. Y. Ogura, T. Nishimura, and J. Tanida, "Nanoscale logic operation in optically manipulated micro-droplets," Proc. SPIE **7764**, 77640H (2010).
4. M. Zheng, Y. Ogura, and J. Tanida, "Three-dimensional dynamic optical manipulation by combining a diffractive optical element and a spatial light modulator," Opt. Rev. **15**, 105–109 (2008).

Fundamental Study on Hybrid Phase-Coding and Spatial Multiplexing for Holographic Data Storage

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Abstract:
Starting with the numerical calculation of the Fourier spectrum of the orthogonal phase-coded beam, a fundamental study on hybrid phase-coding and spatial multiplexing shows that there will be a complex and serious fluctuation in both intensity and phase distribution in the reference beam if a Fourier transform configuration is used for setting up the reference beam. In order to maintain phase-only modulation and orthogonality in the reference beam pattern, we suggest that the phase modulator should be imaged to the recording plane.

OCIS codes: Holography: 090.4220 Multiplex holography, Optical data storage: 210.1635 Coding for optical storage, Fourier optics and signal processing: 070.0070.

1. Introduction

In a practical holographic storage system both the storage density and the quality of the reconstructed data are critical. In order to reach high storage density in relatively thin material (such as photopolymer films designed for disk-type holographic storage) some kinds of multiplexing techniques have been studied, among which speckle-shift multiplexing technique appears attractive owing to the high correlation selectivity. However, the results of our previous work [1] showed that the reference beam with randomly encoded phase may arouse noise coming into the reconstructed images. In terms of noise suppression, orthogonal phase-coding multiplexing has particular advantage (see, for example, refs [2, 3]). So, a hybrid multiplexing method, which incorporates orthogonal phase-coding multiplexing into spatial-multiplexing, has been considered recently [4, 5].

In the early work on orthogonal-phase coding, many data pages were stored in a single interaction region of the storage medium. Each hologram had a unique address code which was assigned to the reference beam through a phase-modulating device in combination with a computer-generated hologram (CGH). Each encoded reference beam contained many plane sub-beams, and the interference between the phase-coded sub-beams was ignored in the analysis of the early work. In the concept of hybrid phase-coding and spatial multiplexing (PCSM), all holograms will be recorded with a single phase-coded reference beam, and should be distinguished from each other in the readout stage by the position selectivity of the reference beam. For system simplicity it is desired to realize the phase coding by a single phase modulator, without the need of a CGH device.

In the preliminary research on PCSM, the position selectivity of phase-coded reference beam has been proved, but high quality storage of high-resolution data pages has not yet demonstrated. For implementation of high density and high quality data storage with PCSM, a thorough study on the fundamentals of PCSM, including the general principle and the optimized configuration, is necessary. In this paper, we investigate some fundamental aspects starting with the calculation of the complex Fourier spectrum of an orthogonal phase coded reference beam.

2. Physical Modeling

The building up of an orthogonal phase-coded beam is shown in figure 1(a). A plane beam is reflected by the phase modulator, LCOS, on which an orthogonal phase-coded data page is loaded, so that the beam is orthogonally phase modulated. To transfer the beam to a reference a popular way is to bring it to the recording medium through a lens as shown in figure 1(b). In this case the reference beam is the Fourier spectrum of the phase pattern.

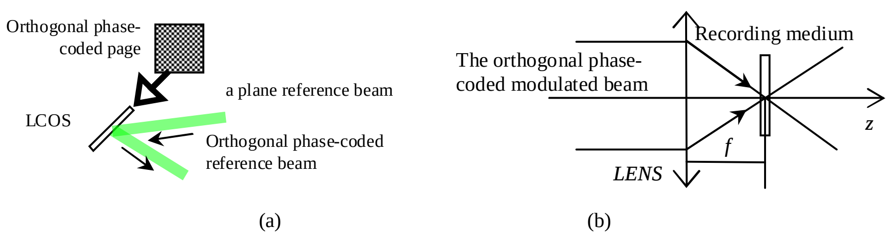

Fig.1 The scheme of building up of the orthogonal phase-coded beam (a), and the Fourier transform configuration for the reference beam (b).

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If the phase code is a $2^n \times 2^n$ array (n is an integer) generated by Walsh-Hadamard method [2], and the LCOS device is perfect, the light field distribution on the LCOS, $f_n(x_0, y_0)$, can be considered as a combination of $2^n \times 2^n$ square pixels through Walsh-Hadamard transformation of n times. Thus, the complex amplitude of the reference beam is the Fourier transform of $f_n(x_0, y_0)$, and can be calculated iteratively according to the following equation:

$$F_n(x, y) = 2^n \Delta^2 \mathrm{sinc}(\Delta f_x)\mathrm{sinc}(\Delta f_y)\prod_{n=0}^{n}\{\cos[p\Delta 2^{n-1}(f_x + f_y)] - j\sin[p\Delta 2^{n-1}(f_x - f_y)]\} \quad (1)$$

where Δ indicates the pixel size of the LCOS, (x, y) are the coordinates in the surface of the material, and $f_x = x/lf$, $f_y = y/lf$, f is the focal length of lens, l is the wavelength used.

3. Results of Numerical Calculation

Using equation (1) we have calculated the Fourier Transform of $f_8(x_0,y_0)$, a 256×256 (n=8) orthogonal phase-code modulated beam. The pattern of $f_8(x_0,y_0)$ is shown in Fig.2. The parameters used for calculation are: Δ=19µm, l=457nm, and f=75mm.

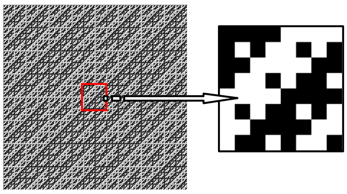
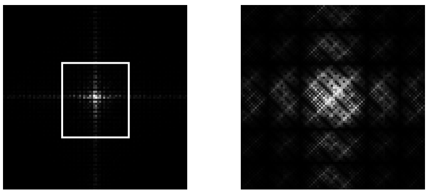


Fig.2 A $2^8 \times 2^8$ orthogonal phase-coded page and the enlarged central 8×8 area.

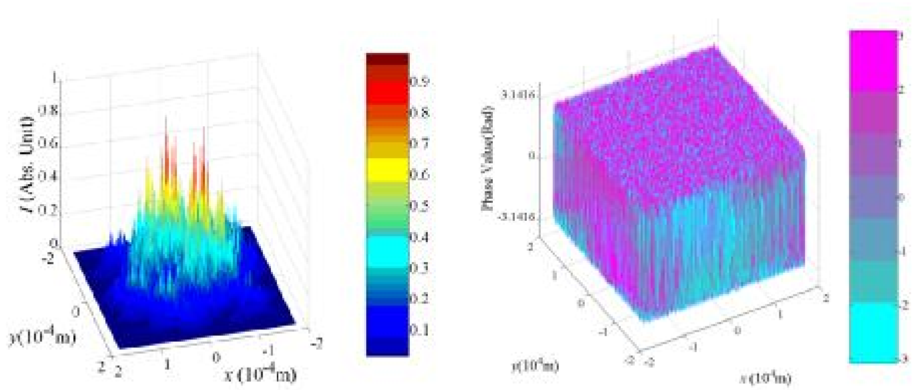
The calculated 2-D intensity distribution of $F_8(x, y)$ is shown in Fig. 3. In Fig. 3(a) it looks like the Fourier spectrum of a squared aperture with size of Δ. However, when the sampling interval goes smaller, the complicated intensity distribution is unveiled, as shown in Fig.3 (b).



(a) (b)

Fig.3 The intensity of the Fourier spectrum of a $2^8 \times 2^8$ orthogonal phase-coded beam. The sampling interval is (a)10*m*m, and (b) 1*m*m.

According to the parameters, the main lobe takes up the central 361× 361*m*m area. In order to investigate the detailed intensity (normalized by the value at the origin) and phase distribution within the main lobe, we reduced the sampling interval to 0.361*m*m. The calculated results are shown in figure 4 in 3-D viewing format.



(a) (b)

Fig.4 The distribution of intensity, *I*, (a) and phase value (b) as function of 2-D coordination within the main lobe of the Fourier spectrum.

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It is clear in Fig.4 that there is a complex and serious fluctuation in both intensity and phase distribution. According to the principle of holography, the useful diffraction order is modulated by the intensity of reference light, so the complicated intensity distribution has an influence on the quality of the reconstructed image. Moreover, the phase is no longer binary but almost varying continuously between –*p* and *p*, which will reduce the phase orthogonality.

4. Consideration for Configuration Design

According to the above discussion, it is necessary to optimize the orthogonal phase-coded beam in PCSM by careful configuration design. In order to maintain phase-only modulation and orthogonality between any two columns (or rows) of the reference beam pattern, we suggest that the phase modulator should be imaged to the recording plane.

5. Conclusions

A fundamental study on hybrid phase-coding and spatial multiplexing starting with the numerical calculation of the Fourier spectrum of the orthogonal phase-coded beam has been conducted. The results showed that there is a complex and serious fluctuation in both intensity and phase distribution if a Fourier transform configuration is used for reference beam. Moreover, the phase is not longer binary (0 or *p*) but varying continuously between –*p* and *p*, this may reduce the phase orthogonality and is not desired for PCSM. Also the additional intensity distribution will influence the quality of the beam. A solution we suggested is an alternative imaging configuration for the reference beam. Deeper researches on the principle and configuration are still in progress.

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6. References

[1] Wei Song, Shiquan Tao, Dayong Wang, "Investigation on influence of wavefront property of reference beams on the quality of images reconstructed from holograms," in Optical Data Storage 2010, Susanna Orlic, Ryuichi Katayama, eds., Proceedings of SPIE Vol. 7730, p77301V (2010)

[2] C.Denz, G.Pauliat, G.Roosen, and T.Tschudi, "Volume hologram multiplexing using a deterministic method," Opt. Comm., 85:171-176(1991)

[3] C. Denz, K. –O. Muller, F. Visinka, and T.Tschudi, "A Demonstration Platform for Phase-Coded Multiplexing" in *Holographic Data Storage*, H. J. Coufal, D. Psaltis, G. T. Sincebox, eds. (Springer, 2000)

[4] Wei Song, Shiquan Tao, Qianli Zhai, and Yuhong Wan, "The feasibility research on phase-shift multiplexing for holographic storage," in Information Optics and Optical Data Storage, Feijun Song, Shiquan Tao, Francis T. S. Yu, Suganda Jutamulia, Kees A. Schouhamer Immink, Keiji Shono, eds., Proc. of SPIE Vol. 7851, p78510E (2010)

[5] Satoshi Honma , Shinzo Mutoa, Atsushi Okamotob, "Shift-phase code multiplexing technique for holographic memories and optical interconnection," in Holography and Diffractive Optics III, edited by Yunlong Sheng, Dahsiung Hsu, Chongxiu Yu, Proc. of SPIE Vol. 6832, 68322P, (2007)

Cross-sectional Imaging of Paper Sheet by Common-path Swept Source Optical Coherence Tomography

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Abstract: A common-path swept source optical coherence tomography (SS-OCT) is a promising method for a stable cross-sectional imaging of high-speed translating samples. We demonstrate a cross-sectional imaging of paper sheets by a common-path SS-OCT system.
OCIS codes: (110.4500) Optical coherence tomography; (120.3180) Interferometry; (120.4820) Optical systems

1. Introduction

Optical coherence tomography (OCT) is a powerful tool for obtaining a cross-sectional image of an internal structure of scattering media with high axial resolution [1]. Although OCT became one of the essential techniques for biomedical applications, especially ophthalmic diagnostics, few industrial applications have been reported.

In our previous study, we have proposed to apply OCT to identification of valuable paper sheets such as gift coupons, tickets, and cheques [2]. In this application, it is often required that identifications can be executed with samples conveyed at an extremely high speed up to 2,000-3,000 mm/sec. Spectral domain OCT (SD-OCT) and swept source OCT (SS-OCT), which are known as Fourier domain OCT, promise to enable high-speed imaging [3]. It has also been reported that SS-OCT is superior to SD-OCT in reducing motion artifacts of a sample [4,5]. In Fourier domain OCT, depth information can be obtained with a reference mirror fixed its position in the interferometer. This fact enables a common-path design of the interferometer where the sample and reference arms share a same beam path. The common-path interferometer can increase the interferometer stability and is less sensitivity to vibrations than a two-arms-type interferometer [6,7]. This common-path approach also has advantages that the dispersion and polarization mismatch caused by optical elements in the interferometer are automatically compensated. Therefore, an SS-OCT system with a common-path interferometer is considered to be suitable for an implementation of the high-speed OCT imaging of samples conveyed at a high speed.

In this work, we constructed a compact common-path SS-OCT system and demonstrated a cross-sectional imaging of valuable paper sheets in which a security thread made by ribbon shaped metal-coated film is embedded, by shifting the sample sequentially in the transverse direction. This compact system enables us to develop a tomographic imaging system for the high-speed inspection of valuable paper sheets.

2. Experimental setup

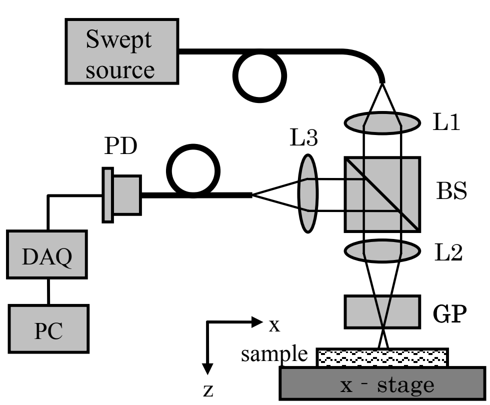

Fig. 1. Experimental setup of the common-path SS-OCT.

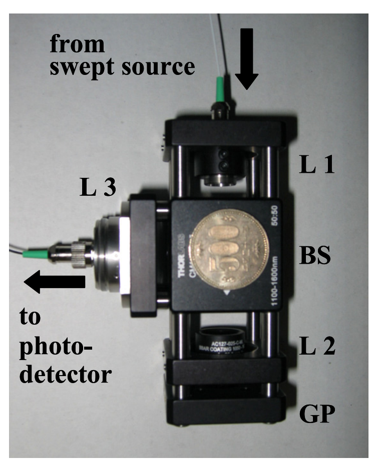

Fig. 2. Photograph of the common-path interferometer.

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Figure 1 shows a schematic diagram of our common-path SS-OCT system. Figure 2 shows a photograph of the common-path interferometer constructed in the present work. The light source was a wavelength-swept laser (HSL-2100-HS, Santec) consists of a fiber ring cavity with a semiconductor amplifier and polygon-scanner-based wavelength filter. The laser generates light at a central wavelength of 1,335 nm with a maximum output power of 29 mW. The scanning range of the laser was 99 nm over 3 mW output power. The laser was operated at a scanning rate of 50 kHz and the duty cycle was 99.9%. The light emitted from the swept-source laser was guided into a common-path interferometer through a single-mode optical fiber. The common-path interferometer consists of a collimator lens L1 (f = 8 mm), a 50/50 cubic beam splitter BS, an objective lens L2 (f = 25 mm), a glass plate GP with a thickness of 3 mm, and a focusing lens L3 (f = 18.4 mm). The GP was set such that its back surface, near the front surface of a sample, was placed at the focus of the objective lens L2. The back surface of GP serves as a reference mirror. The light reflected from the reference mirror and the light from the sample propagated back the common path and were coupled into another single-mode optical fiber by the focusing lens L3. The interference signal as a function of time was detected by an InGaAs photodetector PD (PDB150C, Thorlabs, Inc.) at the exit of the optical fiber and digitized using a data acquisition board DAQ (ATS9462-S, Santec) with a 16-bit resolution and a sampling rate of 125 Mpoint/s. The digitized data was interpolated to correct the nonlinearity in frequency sweep as a function of time before DFT processing to retrieve depth profiles, i.e., reflective profiles along the depth, of the sample.

The point spread function (PSF) of our SS-OCT system measured using an Au-coated mirror as a sample is shown in Fig. 3. The full-width at half maximum axial resolution was estimated to be 14.3 μm from this PSF.

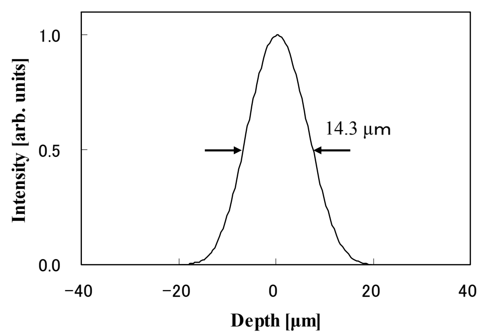

Fig. 3. Point spread function (PSF) measured using a mirror as a sample. FWHM axial resolution was estimated to be 14.3 μm in air.

3. Experimental results

Using our SS-OCT system, we demonstrated a cross-sectional imaging of valuable paper sheets in which a security thread of a ribbon shaped metal-coated plastic film with a width of about 1mm is embedded. The paper sheet used as a sample is approximately 100 μm in thickness and the security thread is embedded around the central depth of the paper.

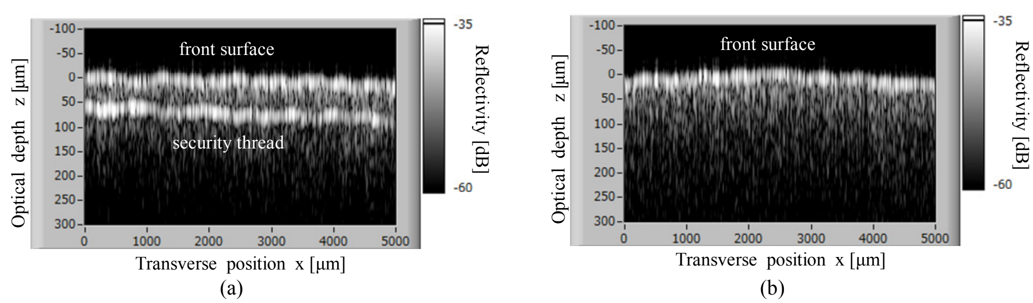

Fig. 4. Cross-sectional OCT images obtained at (a) the security thread region and (b) the no-security-thread region. Each image is composed of 500 × 400 (transverse × depth) pixels.

Figure 4(a) shows a cross-sectional OCT image of the sample paper sheet where the security thread is embedded. Figure 4(b) also shows a cross-sectional OCT image of the sample paper sheet where the security thread is absent. The cross-sectional images were obtained by measuring depth profiles at multiple transverse positions by shifting the sample sequentially in the transverse direction. The cross-sectional images is 5.0 × 0.4 mm^2 (transverse × depth) in size and consists of 500 × 400 pixels. The images are displayed as the reflectivity using a logarithmic gray-scale. The bright line along the transverse direction at the optical depth of approximately 0 μm in each image corresponds to the front surface of the sample. The security thread embedded in the paper sheet is clearly imaged at the optical depth of approximately 60 μm, as shown in Fig. 4(a). It can be definitely identified whether the security thread is present or absent from Figs. 4(a) and 4(b).

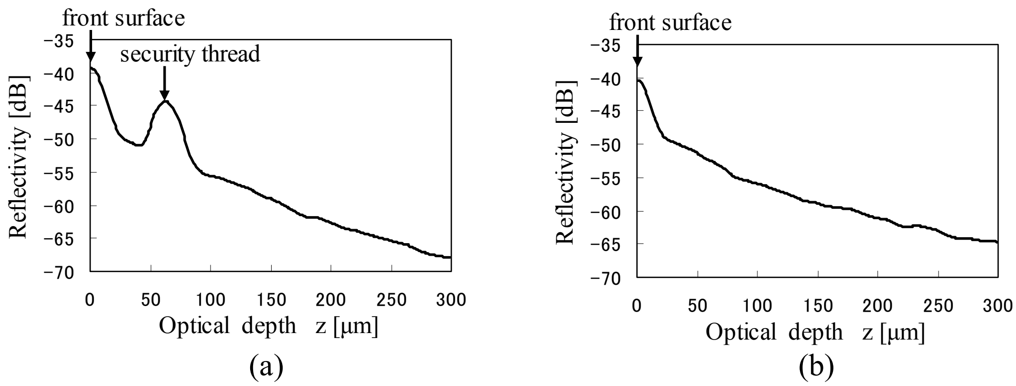

Fig. 5. Averaged reflectivity depth profiles obtained from the data constructing the cross-sectional image shown in (a) Fig. 4(a) and (b) Fig. 4(b).

Figure 5(a) and 5(b) shows graphs of the averaged depth profile which are obtained by averaging depth profiles at all transverse positions in the cross-sectional image of Figs. 4(a) and 4(b). In our previous work, we demonstrated the cross-sectional imaging of the same sample used in the present work using the SD-OCT system using a superluminescent diode (SLD) light source with a center wavelength of 898 nm [2]. Comparing the averaged depth profile shown in Fig. 4(a) with that presented in the previous work, it is found that the decrease in the signal peak value of the security thread relative to that of the front surface is improved by approximately 10dB. This is because the increase of a central wavelength of the light source from 898 to 1,335 nm reduces the optical scattering and increases the penetration depths.

4. Conclusion

To realize the high-speed OCT imaging of valuable paper sheets conveyed at a high speed for inspection, we constructed a compact SS-OCT system with a common-path interferometer. Using the common-path SS-OCT system, a cross-sectional imaging of valuable paper sheets in which a security thread is embedded was demonstrated by shifting the sample sequentially in the transverse direction. In future work, we plan to perform an imaging of valuable paper sheets conveyed on a high-speed motorized stage and then estimate the scattering property of the paper sheets.

5. References

[1] D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, and J. G. Fujimoto, "Optical Coherence Tomography," Science **254,** 1178-1181 (1991).

[2] K. Fujiwara and O. Matoba, "Detection and Evaluation of Security Features Embedded in Paper Using Spectral-Domain Optical Coherence Tomography," Opt. Rev. **18**, 171-175 (2011).

[3] W. Drexler and J. G. Fujimoto, Optical Coherence Tomography (Springer, New York, 2008), Chap. 1.

[4] S. H. Yun, G. J. Tearney, J. F. de Boer, and B. E. Bouma, "Motion artifacts in optical coherence tomography with frequency-domain ranging," Opt. Express **12**, 2977-2998 (2004).

[5] S. H. Yun, G. J. Tearney, J. F. de Boer, and B. E. Bouma, "Pulsed-source and swept-source spectral-domain optical coherence tomography with reduced motion artifacts," Opt. Express **12**, 5614-5624 (2004).

[6] A. B. Vakhtin, D. J. Kane, W. R. Wood, and K. A. Peterson, "Common-path interferometer for frequency-domain optical coherence tomography," Appl. Opt. **42**, 6953-6958 (2003).

[7] K. M. Tan, M. Mazilu, T. H. Chow, W. M. Lee, K. Taguchi, B. K. Ng, W. Sibbett, C. S. Herrington, C. T. A. Brown, and K. Dholakia, "In-fiber common-path optical coherence tomography using a conical-tip fiber," Opt. Express **17**, 2375-2384 (2009).

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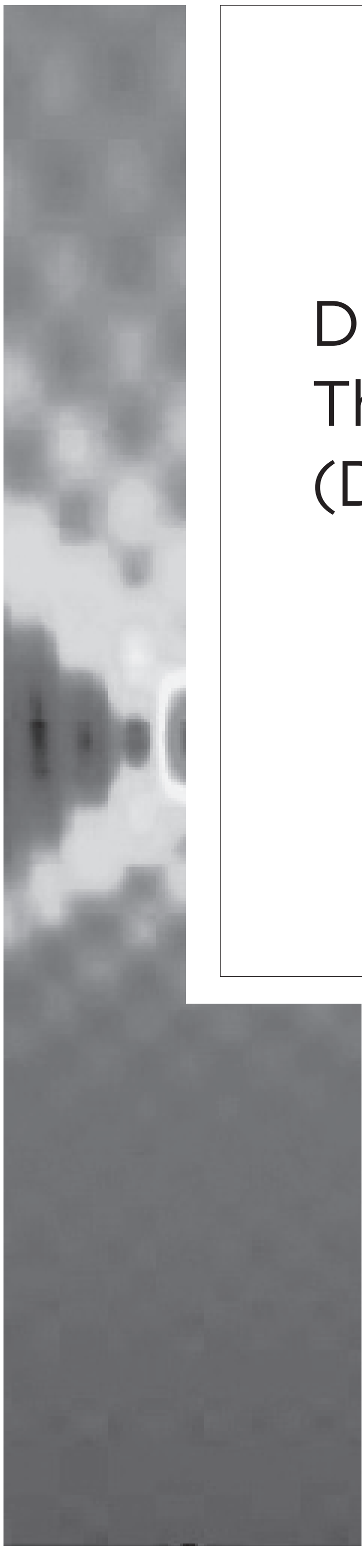

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