出國報告（出國類別：國際會議）

2015 年國際全像及相關技術研討會

International Workshop on Holography and Related Technologies 2015 (IWH 2015)

服務機關：國立中央大學
姓名職稱：孫慶成 教授
派赴國家：日本
出國期間：2015.11.30~2015.12.2
報告日期：2015.12.25

摘要

本人以及研究團隊成員前往日本沖繩(Okinawa, Japan)參加 2015.12.01 (二)~ 2015.12.03(四)舉行之 2015 年國際全像及相關技術研討會(International Workshop on Holography and Related Technologies 2015, IWH 2015)，於研討會期間研究團隊發表三篇論文，分享本團隊在全像相關領域之研究成果，並聆聽與會者在全像技術領域的研究成果以及想法，有助於提升計畫的研發層次以及產生其他在研究上的創新想法。

目錄

壹、目的

此次去日本沖繩(Okinawa, Japan)參加於 2015.12.01 (二)~ 2015.12.03(四)舉行之 2015 年國際全像及相關技術研討會(International Workshop on Holography and Related Technologies 2015, IWH 2015)，本研究團隊以邀請(Invited)以及口頭報告(Oral)方式發表了三篇研究成果。與會期間除了分享本團隊在全像關領域的研究成果外，並同時聆聽其他國內外研究團隊在全像以及相關領域之研究成果以及應用，有助於本研究團隊提升研發的層次。

貳、過程

2015 年國際全像及相關技術研討會(International Workshop on Holography and Related Technologies 2015, IWH 2015)在日本沖繩宜野灣市(Ginowan)的沖繩會議中心(Okinawa Convention Center)舉行，與會者人數約 80 人左右，投稿文章總計 57 篇，包含 3 篇全會談話(Plenary Talk)、15 篇邀請演講(Invited Talk)、19 篇口頭報告(Oral)以及 20 篇壁報展示(Poster)。會議第一天(2015.12.01)主要是全會談話(Plenary Talk)、邀請演講(Invited Talk)以及口頭報告(Oral)，領域分別是全像術(Holography)、3D 顯示技術(3D Display)以及全像儲存器技術(Holographic Memory)，以及晚上參加晚宴。第二天(2015.12.02)以邀請演講(Invited Talk)、口頭報告(Oral)以及壁報展示(Poster)為主，演講領域分別有全像儲存器技術(Holographic Memory)、3D 成像技術(3D Imaging)、3D 顯示技術(3D Display)、量測技術以及數位全像術(Measurement and Digital Holography)以及壁報展示(Poster Session)；第三天的主題是量測技術(Measure)以及元件以及全像片相關計算方法(Devices and Hologram Calculations)。本研究對團隊三篇研究成果被歸類在全像儲存器技術(Holographic Memory)以及量測技術以及數位全像術(Measurement and Digital Holography)中，論文標題分別是用剪切式干涉儀於全像光學儲存之同差檢測(Homodyne Detection of Holographic Optical Storage Technique using Shearing Interferometer)、同軸式全像儲存系統紀錄介質離焦之研究(An Optical Study on Defocusing out of Recording Media of Collinear Holographic Data Storage)、藉由數位光學相位共軛方式做散射抑制(Scattering Suppression by Digital Optical Phase Conjugator)，其中第一篇為本人之大會邀請演講(Invited Talk)，另外兩篇分別為本團隊之鄭智元博士生以及余業緯博士後研究員

的口頭報告(Oral)。大會邀請演講時間為 30 分鐘，前 25 分鐘演講者進行報告，後 5 分鐘接受與會者發問；口頭報告時間則是 15 分鐘，前 12 分鐘進行口頭報告，後 3 分鐘接受與會者提問。與會期間，本人以及本團隊發表期間，多位參與者對本團隊的研究成果提出問題，於交流過程中給予本團隊寶貴的經驗以及建議。其中鄭智元博士生所發表的論文，與日本 Sony 公司前研究員 Akio Yamakawa 共同署名作者，記錄介質離焦概念由 Yamakawa 先生所提供。與會者提出為何離焦距離為特定值時，該博士生回答不知道，數據由 Yamakawa 先生所提供。回答的結果令我不滿意，於中場休息時間時指正應該如何應答才恰當，這也是給博士生訓練於演講場合時，應該如何應答的機會。除了論文發表以及口頭報告外，本團隊議在會議前間聆聽與討論其他研究團隊的研究成果，以求掌握其他研究團隊最新的研究成果，提升計畫的研究層次，期望在研究方面激發出更多的創意與成果。其中印象深刻有日本和歌山大學(Wakayama University) Takanori Nomura 教授研究團隊所發表的文章“Experimental Demonstration of Super-resolution Holographic Data Storage”，該篇文章內容講述在全像儲存中的超解析度，言下之意是如何使更小的輸入影像成像清晰，這有助於本研究團隊提升讀取的影像有更高的訊雜比以及更低的誤碼率，亦有助於儲存系統儲存容量的提升。交通大學林烜輝教授團隊發表的文章“Novel Holographic Recording in Phenanthrenequinone-doped Poly(methyl methacrylate) Photopolymer”，此文章主要是研究關於全像儲存系統中所使用的紀錄材料，也就是碟片的主要成分。紀錄材料的優劣取決於讀取時繞射訊息品質的好壞以及存入材料的資訊可以保存的時間，這篇文章可了解目前全像儲存材料最新的研發狀況。另外由韓國首爾國立大學(Seoul National University) Byoungho Lee 教授研究團隊所發表的文章“Use of Holographic Optical Elements for 3D Display”，此篇文章主要介紹利用全像光學元件應用在 3D 顯示技術上。目前虛擬實境(virtual reality)顯示技術在快速發展，到 2016 年時有數家公司推出相應的產品，整體趨勢為虛擬實境中以 3D 影像顯示，在各領域上都有突破性的應用。

参、心得與建議

本研究團隊在此次 IWH 2015 研討會中，展現了在全像技術方面的精進與研究成果，受到與會者的肯定。近年來受到雲端儲存、娛樂產業、3D 影像顯示…等技術的發展，高容量儲存技術的需求愈來愈高，其中光學儲存技術受到矚目，可做到體積小以及大儲存容量的地步，因此全像儲存技術為未來發展的光學儲存技術之一。與光電科學相關的技術充斥在我們生活周遭，又光電科學技術衍生出相關製品亦改變我們生活方式以及消費模式，牽動全球市場在不同領域的需求，影響全球經濟甚鉅。當前應該思考如何促進光電科學相關技術如何使全世界進步，以及如何使下世代年輕人對光電科學或是基礎科學產生興趣並投入，皆是我輩極需深思的問題。

在參加此屆 IWH 研討會過程中，除了日本有較多的與會者之外，台灣方面只有少數團隊餐與研討會，實屬可惜。期望下次 IWH 研討會能在台灣舉行，期望有更多國內研究團隊參與盛會，前來發表並分享研究成果，相信有助於台灣科技產業與研究團隊的成長，使更多國內外人士了解台灣在科技與研發上的努力與優異表現。

肆、附錄

1. 攜回 2015 年國際全像及相關技術研討會(International Workshop on Holography and Related Technologies 2015, IWH 2015)紙本論文集一本。

2. 照片：

1. 本人演講情形。

2. 余業緯博士後研究員口頭報告情形。

3. 本人於晚宴時受邀致詞。

4. 於會場講者正在報告。

3. 大會議程表與本團隊投稿論文

Tuesday, December 1st, 2015

9:00-10:00 Registration

10:00-10:05 Opening Remark

10:05-11:55

Tu1 Holography

Presider: Prof. Osamu Matoba

Tu1-1 10:05-10:45 Plenary

Holographic Correloscopy for Imaging a 3-D Object Hidden behind a Diffuser: A Review, Mitsuo Takeda[1], Alok Kumar Singh[2], Dinesh Narayana Naik[3], Giancarlo Pedrini[2], Wolfgang Osten[2]; [1]Center for Opt. Res. & Edu. (CORE), Utsunomiya University, Japan; [2]Institut für Technische Optik (ITO), University of Stuttgart, Germany; [3]School of Physics, University of Hyderabad, India

Tu1-2 10:45-11:25 Plenary

Recent Advance of Photorefractive Polymers and Updatable 3D Holographic Display, Naoto Tsutsumi, Kenji Kinashi, Wataru Sakai; Faculty of Material Science & Engineering, Kyoto Institute of Technology, Japan

Tu1-3 11:25-11:55 Invited

Novel Holographic Recording in Phenanthrenequinone-doped Poly(methyl methacrylate) Photopolymer, Shiuan Huei Lin[1], Vera Marinova[2,3], Ken-Yu Hsu[2]; [1]Department of Electrophysics, National Chiao Tung University, Taiwan; [2]Department of Photonics, National Chiao Tung University, Taiwan; [3]Institute of Optical Materials and Technologies, Bulgaria

11:55-13:00 Lunch

13:00-15:00

Tu2 3D Display 1

Presider: Prof. Jung-Ping Liu

Tu2-1 13:00-13:30 Invited

Development of Scanning Holographic Displays, Yasuhiro Takaki; Institute of Engineering, Tokyo University of Agriculture and Technology, Japan

Tu2-2 13:30-14:00 Invited

Volumetric Display with Holographic Parallel Optical Access, Kota Kumagai, Yoshio Hayasaki; Center for Optical Research and Education (CORE), Utsunomiya University, Japan

Tu2-3 14:00-14:30 Invited

360 Degree Contents Processing for Realistic 3D Image Display, Xiaodi Tan[1], Xin Luo[1], Hideyoshi Horimai[2,3]; [1]Beijing Institute of Technology, China; [2]HolyMine Corporation, Japan; [3]3Dragons LLC, Japan

Tu2-4 14:30-15:00 Invited

Holographic 3D-image Printer System with Collinear Optics, Hideyoshi Horimai; HolyMine Corporation, Japan

15:00-15:30 Coffee break

15:30-17:30

Tu3 Holographic Memory 1

Presider: Prof. Ryushi Fujimura

Tu3-1 15:30-16:00 Invited

Hybrid Organic-inorganic Holographic Elements, Vera Marinova[1,2], Shiuan Huei Lin[3], Yi Hsin Lin[1], Ken Y. Hsu[1]; [1]Department of Photonics, National Chiao Tung University, Taiwan; [2]Institute of Optical Materials and Technologies, Bulgaria; [3]Department of Electrophysics, National Chiao Tung University, Taiwan

Tu3-2 16:00-16:15

Focus-Shift Multiplexing Technique by Wavefront Modulation for Self-referential Holographic Data Storage, Masanori Takabayashi, Taisuke Eto, Takashi Okamoto; Department of Systems Design and Informatics, Kyushu Institute of Technology, Japan

Tu3-3 16:15-16:30

Experimental Demonstration of Super-resolution Holographic Data Storage, Teruyoshi Nobukawa[1,2], Takanori Nomura[3]; [1]Graduate School of Systems Engineering, Wakayama University, Japan; [2]Research Fellow of the Japan Society for the Promotion of Science, Japan; [3]Faculty of Systems Engineering, Wakayama University, Japan

Tu3-4 16:30-16:45

Phase Encoding based on Unequally Spaced Quanternary Level in Holographic Data Storage, Ke Xu, Yong Huang, Xiao Lin, Yabin Cheng, Xiaotong Li, Xiaodi Tan; Beijing Institute of Technology, China

Tu3-5 16:45-17:00

Writing and Reading Characteristics of Time Sequential Angle-multiplexed Holographic Memory, Yuki Hayashi[1], Ryushi Fujimura[2], Masao Endo[1], Shinsuke Umegaki[1], Tsutomu Shimura[1]; [1]Institute of Industrial Science, The University of Tokyo, Japan; [2]Utsunomiya University, Japan

Tu3-6 17:00-17:15

2-Dimensional Signal Processing for RLL High Density Recording in Holographic Data Storage System, Kazuyuki Tajima, Yusuke Nakamura, Taku Hosizawa; Center for Technology Innovation-Information and Telecommunications, Hitachi Ltd., Japan

Tu3-7 17:15-17:30

Data Coding Method for Optical Correlator with Coaxial Holographic System, Kanami Ikeda, Suguru Wakita, Eriko Watanabe; University of Electro-Communications, Japan

---

18:00-20:00 Welcome Reception

Wednesday, December 2nd, 2015

8:00-9:00 Registration

9:00-10:30

We1 Holographic Memory 2

Presider: Prof. Tsutomu Shimura

We1-1 9:00-9:30 Invited

Homodyne Detection of Holographic Optical Storage Technique using Shearing Interferometer, Yeh-Wei Yu, Shuai Xiao, Ching-Cherng Sun; Department of Optics and Photonics, National Central University, Taiwan

We1-2 9:30-10:00 Invited

Angular Multiplexing Holographic Memory with the Help of Computer-generated Hologram, Takanori Nomura[1], Toshiyuki Morimoto[2], Teruyoshi Nobukawa[2]; [1]Faculty of Systems Engineering, Wakayama University, Japan; [2]Graduate School of Systems Engineering, Wakayama University, Japan

We1-3 10:00-10:15

An Optical Study on Defocusing out of Recording Media of Collinear Holographic Data Storage, Chih-Yuan Cheng[1], Yeh-Wei Yu[1], Ching-Cherng Sun[1], Yawara Kaneko[2], Akio Yamakawa[3]; [1]Department of Optics and Photonics, National Central University, Taiwan; [2]Teikyo Heisei University, Japan; [3]Nissei Technology Corporation, Japan

We1-4 10:15-10:30

Diffraction Characteristics of Volume Polarization Holography Recorded with Orthogonally Linear Polarization Light, Jinliang Zang[1], Guoguo Kang[1], An'an Wu[1], Ying Liu[1], Yong Huang[1], Xiaodi Tan[1], Tsutomu Shimura[2], Kazuo Kuroda[1,3]; [1]School of Optoelectronics, Beijing Institute of Technology, China; [2]Institute of Industrial Science, The University of Tokyo, Japan; [3]Center for Optical Research and Education (CORE), Utsunomiya University, Japan

10:30-11:00 Coffee break

11:00-12:00

We2 3D Imaging

Presider: Prof. Yasuhiro Awatsuji

We2-1 11:00-11:30 Invited

Three-dimensional Pupil Engineered Holographic Imaging, Xiaomin Zhi[1,2], Po-Hao Wang[1,2], His-Hsun Chen[1,3], Wei-Tang Lin[1,2], Yuan Luo[1,2]; [1]Institute of Medical Devices and Imaging, National Taiwan University, Taiwan; [2]Molecular Imaging Center, National Taiwan University, Taiwan; [3]Department of Electrical Engineering and Graduate Institute of Photonics and Optoelectronics, National Taiwan University, Taiwan

We2-2 11:30-12:00 Invited

Three-Dimensional Imaging with Stereo-illumination by Optical Scanning Holography, Jung-Ping Liu[1], Sheng-Yen Wang[1]; [1]Department of Photonics, Feng Chia University, Taiwan

12:00-13:00 Lunch

13:00-14:40
We3 3D Display 2
Presider: Prof. Takanori Nomura

We3-1 13:00-13:40 Plenary
A Multi-directional Screen for Glasses Free 3D Display with a Novel Nano-patterning System for Large Area, Wen Qiao[1], Wenqiang Wan[1], Ming Zhu[2], Linsen Chen[2]; [1]Collaborative Innovation Center of Suzhou Nano Science and Technology, Soochow University, China; [2]National United Center of Micro/Nano Manufacturing, SVG Optronics Corporation, China

We3-2 13:40-14:10 Invited
Use of Holographic Optical Elements for 3D Display, Byoungho Lee, Changwon Jang; School of Electrical Engineering, Seoul National University, Korea

We3-3 14:10-14:40 Invited
Computer Generated Holographic Display using Angular-spectrum Layer-Oriented Algorithm, Yan Zhao, Liangcai Cao, Hao Zhang, Qingsheng He, Guofan Jin; Department of Precision Instruments, Tsinghua University, China

14:40-15:00 Coffee break

15:00-16:30

We4 Measurement and Digital Holography

Presider: Prof. Nobukazu Yoshikawa

We4-1 15:00-15:15

Optically Sectioned Volume Holographic Endoscopy, Chen Yen Lin[1], Yuan Luo[2,3]; [1]Institute of Photonics and Optoelectronics, National Taiwan University, Taiwan; [2]Institute of Medical Device and Imaging, National Taiwan University, Taiwan; [3]Molecular Imaging Center, National Taiwan University, Taiwan

We4-2 15:15-15:30

Scattering Suppression by Digital Optical Phase Conjugator, Yeh-Wei Yu, Ching-Cherng Sun, Wei-Hsin Chen, Chih-Shun Ho, Szu-Yu Chen, Che-Chu-Lin; Department of Optics and Photonics, National Central University, Taiwan

We4-3 15:30-15:45

On the Optical Measurement of Polymerization Shrinkage: Interferometric Method vs. Holographic Method, Yasuo Tomita; Department of Engineering Science, University of Electro-Communications, Japan

We4-4 15:45-16:00

Demonstration of Phase and Fluorescence Imaging with Dynamics using a Multi-modal Digital Holographic Microscope, Xiangyu Quan[1], Peng Xia[1,2], Kouichi Nitta[1], Osamu Matoba[1], Yasuhiro Awatsuji[3]; [1]Graduate School of System Informatics, Kobe University, Japan; [2]Research Fellow of the Japan Society for the Promotion of Science, Japan; [3]Graduate School of Science and Technology, Kyoto Institute of Technology, Japan

We4-5 16:00-16:15

Multi-wavelength Digital Holography based on Phase-division Multiplexing, Tatsuki Tahara[1], Reo Otani[2], Ryota Mori[1], Yasuhiko Arai[1], Yasuhiro Takaki[3]; [1]Faculty of Engineering Science, Kansai University, Japan; [2]SIGMAKOKI CO., LTD., Japan; [3]Institute of Engineering, Tokyo University of Agriculture and Technology, Japan

We4-6 16:15-16:30

Observing Sound Wave Propagation by using Off-axis Digital Holography, Hiroki Inokuchi[1], Peng Xia[1,2], Kouichi Nitta[1], Osamu Matoba[1], Yasuhiro Awatsuji[3]; [1]Graduate School of System Informatics, Kobe University, Japan; [2]Research Fellow of the Japan Society for the Promotion of Science, Japan; [3]Graduate School of Science and Technology, Kyoto Institute of Technology, Japan

---

17:00-18:30
We5 Poster Session

We5-P1

Investigation of Intensity Distribution of Signal Beam to Increase SNR in Phase-Conjugated Holographic Memory, Tetsuhiko Muroi[1], Yutaro Katano[1], Nobuhiro Kinoshita[1], Norihiko Ishii[1], Nobuo Saito[1]; [1]Science and Technology Research Laboratories, Japan Broadcasting Corporation (NHK), Japan

We5-P2

Numerical Analysis of Inter-page Crosstalk Noise in Holographic Memory System with Multivalued Phase Signal, Kazuki Someya[1], Ryushi Fujimura[1,2]; [1]Department of Optical Engineering, Graduate school of Engineering, Utsunomiya University; [2]Center for Optical Research and Education (CORE), Utsunomiya University, Japan

We5-P3

Evaluation of Randomly Displaced Phase Distribution in Computer Generated Binary Holograms, Shutaro Hiramoto[1], Naoki Ohtani[1], Takashi Fukuda[2], Akira Emoto[1]; [1]Graduate school of Science and Engineering, Doshisha University, Japan; [2]Electronics and Photonics Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Japan

We5-P4

Demonstration of a In-line Polarization Holographic Memory System using PQ/PMMA Photopolymer, Lun Kuang Lin[1], Shiuan Huei Lin[1], Vera Marinova[2,3], Ken Y. Hsu[2]; [1]Department of Electrophysics, National Chiao Tung University, Taiwan; [2]Department of Photonics, National Chiao Tung University, Taiwan; [3]Institute of Optical Materials and Technologies, Bulgaria

We5-P5

Volume Holographic Recording in Photopolymerizable Nanocomposites Incorporating Ultrahigh Refractive Index Hyperbranched Polymer, Shinsuke Takeuchi[1], Ying Liu[2], Naoya Nishimura[3], Takanori Ono[1], Jun-ichiro Takahashi[1], Keisuke Odoi[3], Xiaodi Tan[2], Yasuo Tomita[1]; [1]Department of Engineering Science, University of Electro-Communications, Japan; [2]School of Optoelectronics, Beijing Institute of Technology, China; [3]Chemical Research Laboratories, Nissan Chemical Industries, LTD., Japan

We5-P6

Recording Mechanism in Optical Development Photopolymer, Yuki Takeda[1], Ryushi Fujimura[2], Shinsuke Umegaki[1], Tsutomu Shimura[1]; [1]Institute of Industrial Science, The University of Tokyo, Japan; [2]Department of Optical Engineering, Graduate School of Engineering, Utsunomiya University, Japan

We5-P7

Simultaneous Measurement of Dynamic Vergence and Accommodation Responses to Reconstructed Images of Electro-holography, Aya Nozaki[1], Fumio Okuyama[2], Yuji Sakamoto[1]; [1]Graduate School of Information Science and

Technology, Hokkaido University, Japan; [2]Dept.Medical Information Science, Faculty of Medical Engineering, Suzuka University of Medical Science, Japan

We5-P8

Capture of Large-scaled Wave Fields for Full-color Digitized Holography, Noriaki Sonobe, Yasuhiro Tsuchiyama, Kyoji Matsushima; Department of Electrical and Electronic Engineering, Kansai University, Japan

We5-P9

Fast Calculation Method for Computer-generated Holograms using Geometric Sequence on Fourier Transform Optical System, Takuya Sugawara[1], Yuji Sakamoto[1]; [1]Graduate School of Information Science and Technology, Hokkaido University, Japan

We5-P10

Fast Generation Method of CGH Animation for Viewpoint Movement using Fourier Transform Optical System, Ryosuke Watanabe[1], Yuji Sakamoto[1]; [1]Graduate School of Information Science and Technology, Hokkaido University, Japan

We5-P11

Viewing Zone Expansion Method by Switching LEDs for Holographic HMD Based on Fourier Transform Optical System, Eishin Murakami[1], Ryosuke Watanabe[1], Yuji Sakamoto[1]; [1]Graduate School of Information Science and Technology, Hokkaido University, Japan

We5-P12

Assessment of Autofocus Algorithm for Determining Three-dimensional Position of Moving Phase Object in Digital Holographic Microscope, Naoya Nagahama[1], Peng Xia[1,2], Xiangyu Quan[1], Kouichi Nitta[1], Osamu Matoba[1]; [1]Graduate School of System Informatics, Kobe University, Japan; [2]Research Fellow of the Japan Society for the Promotion of Science, Japan;

We5-P13

Color Digital Holography using Statistical Generalized Phase-shifting Method, Takaaki Shiratori, Nobukazu Yoshikawa; Graduate School of Science and Engineering, Saitama University, Japan

We5-P14

Graphene-based Liquid Crystal Device Fabricated by Photo Alignment Technique, Zhong-Fan Tong[1], Shiuan Huei Lin[1], Vera Marinova[2,3], Ming-Syuan Chen[2], Yi-Hsin Lin[2], Yi-Chun Lai[2], Peichen Yu[2], Ken Y. Hsu[2]; [1]Department of Electrophysics, National Chiao Tung University, Taiwan; [2]Department of Photonics, National Chiao Tung University, Taiwan; [3]Institute of Optical Materials and Technologies, Bulgaria

We5-P15

Computer Generated Hologram for the Light Coding of Stereoscopic Measuring Systems, Yi-Shiang Wang[1], Pei-Qin Du[1], Hsi-Fu Shih[1]; [1]Department of Mechanical Engineering, National Chung Hsing University, Taiwan

We5-P16

Performance Improvement of Volume Holographic Mode De-multiplexer using a Phase Plate for Pre-conversion, Tomokazu Oda[1], Atsushi Okamoto[1], Taketoshi Takahata[2], Shusaku Noda[2], Naoya Wada[3], Akihisa Tomita[1]; [1]Graduate School of Information Science and Technology, Hokkaido University, Japan; [2]OPTOQUEST Co., Ltd., Japan; [3]National Institute of Information and Communications Technology (NICT), Japan

We5-P17

Quantitative Phase Retrieval using Transport of Intensity Equation with Multiple Bandpass Filters, Koshi Komuro[1], Takanori Nomura[2]; [1]Graduate School of Systems Engineering, Wakayama University, Japan; [2]Faculty of Systems Engineering, Wakayama University, Japan

We5-P18

Evaluation of Output Beam Width of Transmitted Light Through the Artificial Scattering Medium with Lamination and Shifted Structure, **Noriyuki Nakatani[1,2], Wen Yan[1], Osamu Matoba[1]; [1]Graduate school of System Informatics, Kobe University, Japan; [2]SCREEN Holdings Co., Ltd., Japan**

We5-P19

Radial Carrier Digital Holography Reconstructing Self-transform Objects, **Ryo Taguchi, Nobukazu Yoshikawa; Graduate School of Science and Engineering, Saitama University, Japan**

We5-P20

Incoherent Digital Holographic Microscopy with 3D Pupil Engineering, **Po-Hao Wang[1,2], His-Hsun Chen[1,3], Wei-Tang Lin[1,2], Yuan Luo[1,2]; [1]Institute of Medical Device and Imaging, National Taiwan University, Taiwan; [2]Molecular Imaging Center, National Taiwan University, Taiwan; [3]Department of Electrical Engineering and Graduate Institute of Photonics and Optoelectronics, National Taiwan University, Taiwan**

Thursday, December 3rd, 2015

8:30-9:00 Registration

9:00-10:30

Th1 Measurement

Presider: Prof. Xiaodi Tan

Th1-1 9:00-9:30 Invited

Recent Progress in Light-in-flight Recording by Holography using a Femtosecond Pulsed Laser, Yasuhiro Awatsuji; Faculty of Electrical Engineering and Electronics, Kyoto Institute of Technology, Japan

Th1-2 9:30-10:00 Invited

Oceanographic Radar for Coastal Ocean Observation, Satoshi Fujii; Faculty of Engineering, University of the Ryukyus, Japan

Th1-3 10:00-10:15

High-speed Phase Measurement by Digital Holographic Microscopy System, Peng Xia[1,2], Naoya Nagahama[1], Xiangyu Quan[1], Kouichi Nitta[1], Osamu Matoba[1], Yasuhiro Awatsuji[3]; [1]Graduate School of System Informatics, Kobe University, Japan; [2]Research Fellow of the Japan Society for the Promotion of Science, Japan; [3]Graduate School of Science and Technology, Kyoto Institute of Technology, Japan

Th1-4 10:15-10:30

Numerical Verification of Ununiform Sampling Lens-Less Fourier Digital Holographic Microscopy, Daisuke Barada[1,2], Shun Kashiwagi[1], Shigeo Kawata[1,2], Toyohiko Yatagai[2]; [1]Graduate School of Engineering, Utsunomiya University, Japan; [2]Center for Optical Research and Education (CORE), Utsunomiya University, Japan

10:30-11:00 Coffee break

11:00-12:15

Th2 Devices and Hologram Calculations

Presider: Prof. Osamu Matoba

Th2-1 11:00-11:30 Invited

Volumetric Holographic Media with Magnetic Artificial Lattices Controlling Optical and Thermal Phenomena, Ryosuke Isogai, Shota Suzuki, Taichi Goto, Hiroyuki Takagi, Yuichi Nakamura, Pang Boey Lim, Mitsuteru Inoue; Toyohashi University of Technology, Japan

Th2-2 11:30-11:45

Holographic Window for Solar Power Generation, Toshihiro Kasezawa[1], Hideyoshi Horimai[1], Hiroshi Tabuchi[2], Tsutomu Shimura[3]; [1]Egarim Co., Japan, Japan; [2]Okamoto Glass Co., Ltd., Japan; [3]Tokyo University, Japan

Th2-3 11:45-12:00

Comparison of Computation Time and Image Quality between CGHs Calculated by the Point Cloud and Polygon-based Method, Noriaki Nakatsuji[1], Kyoji Matsushima[1], Tomoyoshi Ito[2], Tomoyoshi Shimobaba[2]; [1]Department of Electrical and Electronic Engineering, Kansai University, Japan; [2]Graduate School of Engineering, Chiba University, Japan

Th2-4 12:00-12:15

A Simulation Technique for Selection of Color Filter Used for Full-color High-definition CGH, Yasuhiro Tsuchiyama[1], Kyoji Matsushima[1], Sumio Nakahara[2], Yuji Sakamoto[3]; [1]Department of Electrical and Electronic Engineering, Kansai University, Japan; [2]Department of Mechanical Engineering, Kansai University, Japan; [3]Graduate School of Information Science and Technology, Hokkaido University, Japan

12:15-12:20 Closing Remark

Homodyne Detection of Holographic Optical Storage Technique using Shearing Interferometer

Yeh-Wei Yu, Shuai Xiao and Ching-Cherng Sun*

Department of Optics and Photonics, National Central University, Taoyuan City 32001, Taiwan

Summary

The requirement of cold data storage growing with redoulbled speed is challenging current data storage technologies. Holographic data storage technique is doubtless the best solution for the endless growing cold data. In holographic data storage system, phase-modulated signal is proposed to remove the strong DC term in the Fourier plane. Therefore, the efficient consumption of the dynamic range of the medium increases the storage capacity. Comparing to the amplitude-modulated signal, all pixels on the SLM modulated as amplitude "ON" save 50% of laser power. Furthermore, 6 dB SNR enhancement and 3.75 times storage capacity based on coherent addition technique is also demonstrated [1, 2]. For phase signal reading of the collinear system [3-7], the image projection of the signal region is used as the interfering beam on the image sensor [9-10]. However, since the interfering beam passes through the recorded hologram, the wavefront of the interfering beam in the reading process is disturbed seriously. Phase-shifting digital holography is a good idea to resolve the beam disturbance of the recording medium [11]. But the requirement of off-axis digital holography expands the spatial band-width product of the image sensor 4 times, and thus decreases the transfer rate of the system. The 2-steps phase reconstruction with $\pi/2$ phase shift is therefore a reliable solution for both collinear system and off-axis algorithm [12, 13]. However, it inevitably decreases the data transfer rate.

In this paper, we propose shearing interferometer as a high speed solution for homodyne detection. For the experimental demonstration of the method, a simple setup was constructed as shown in Fig. 1. The grating with double frequency is put on the Fourier domain. The first-order diffractions of the two frequency tilt θ_1 and θ_2, respectively. It produces two shearing images in the image sensor. The interference fringe of the shearing images is affected by shifting the grating Δz, and is expressed as

$$I(\xi,\eta)=\frac{2}{\lambda^2 f^2}+\frac{2}{\lambda^2 f^2}\cos\left[kz_d\left(1-\frac{\xi^2+\eta^2}{2f^2}\right)+kx_d\frac{\xi}{f}\right], \tag{1}$$

where λ is the wave length of the light source, f is the focal length of the Fourier lens, k is the wave number, z_d and x_d is the shift of the spectrum in the Fourier domain along z-axis and x-axis, respectively, and are expressed as

$$z_d=\Delta z\tan^2\theta\left(\frac{\cot^2\theta-\tan^2\theta_1}{1+\tan^2\theta_1}-\frac{\cot^2\theta-\tan^2\theta_2}{1+\tan^2\theta_2}\right), \tag{2}$$

$$x_d=\Delta z\tan^2\theta\left(\frac{\left(\cot^2\theta-\tan^2\theta_1\right)\left(\cot\theta\tan\theta_1-1\right)}{1+\tan^2\theta_1}-\frac{\left(\cot^2\theta-\tan^2\theta_2\right)\left(\cot\theta\tan\theta_2-1\right)}{1+\tan^2\theta_2}\right). \tag{3}$$

Where θ is the rotation angle of the grating. We choose θ_1, θ_2 and Δz to make the two diffraction images shearing one pixel with πphase shift. Contributed by the shifting image subtraction, most of the wavefront variation of the diffraction image is removed. Furthermore, since there is no interfering beam passing through the recording material, the material disturbance effect is avoided. In the experiment, binary phase data is input by the phase-only SLM. Figure 2 shows the experimental result and demonstrates the phase signal is read out by the shearing interferometer.

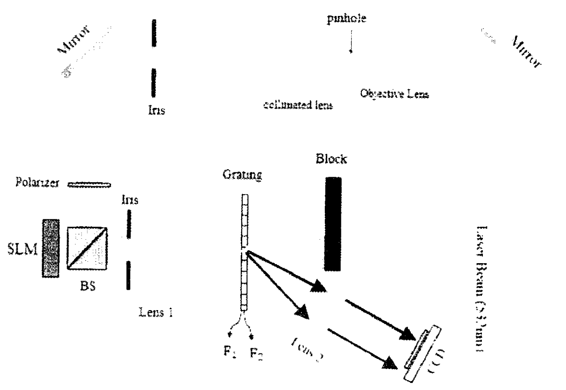

Fig. 1 Experimental setup

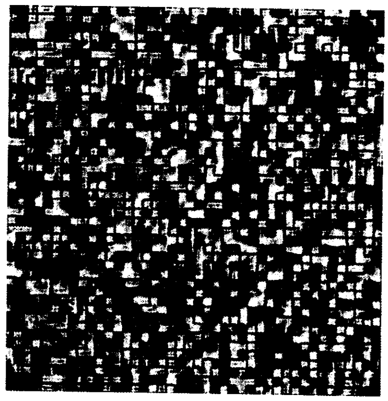

Fig. 2 Intensity distribution of the experimental result

Acknowledgement

This study was sponsored by the National Science Council under grant 104-2221-E-008-078-MY3.

Reference

[1] M. Hara, et. al., Jpn J Appl Phys **47**, 5885–5890 (2008).

[2] K. Curtis, et. al., *Holographic Data Storage: From Theory to Practical Systems* (Wiley, 2010).

[3] H. Horimai et al., Appl. Opt. **44**, 2575–2579 (2005).

[4] K. Tanaka et al., Tech. Digest of ISOM 2007, MO–D–03.

[5] T. Shimura et al., Opt. Lett. **31** 1208-1210 (2006).

[6] C. C. Sun et al., Opt. Express **15**, 18111-18118 (2007).

[7] Y. W. Yu et al., Opt. Lett. **35,** 1130-1132 (2010).

[8] H. Horimai, U. S. Patent **7**,065,032 B2 (2006).

[9] S. Yasuda, et. al., Opt. Lett. **31**, 1639-1641 (2006).

[10] J. Joseph, et. al., Appl. Opt. **45**, 6374-6380 (2006).

[11] T. Nobukawa, et. al., in *Imaging and Applied Optics 2014*, OSA Technical Digest, JTu4A.11 (2014).

[12] M. He, et. al., J. Opt. A **11**, 065705 (2009).

[13] M. R. Ayres, et. al., United States Patent, US 8,233,205 B2 (2012).

An Optical Study on Defocusing out of Recording Media of Collinear Holographic Data Storage

Chih-Yuan Cheng[1], Yeh-Wei Yu[1], and Ching-Cherng Sun[1]*, Yawara Kaneko[2], Akio Yamakawa[3]
[1]Department of Optics and Photonics, National Central University, Chung-Li 32001, Taiwan
[2]Teikyo Heisei University, Tokyo, Japan
[3]Nissei Technology Corporation, Tokyo, Japan
*ccsun@dop.ncu.edu.tw

1. Abstract

In this paper, we derive the diffraction formula based on the VOHIL theory with disc defocus in the recording and reading process. Then we simulate the shift selectivity along x- or y-direction and the shift tolerance along z-direction. Finally we simulate the diffraction pattern distribution with disc defocus and calculate the bit error rate (BER) and signal-to-noise ratio (SNR) of the diffraction pattern.

2. Introduction

There are two types of holographic data storage system: collinear [1] and off-axis [2-3] apparatuses, respectively. In this paper, we consider the disc defocus [4] in the recording and reading process and derive the signal pattern distribution at the detector plane. Then we simulate the pixel shift selectivity with random binary phase modulation [5] along x- or y-direction and tolerance along z-direction. Finally, we simulate the diffraction pattern at the detector plane and calculate the BER and SNR of the diffraction pattern, and then compare the quality of the diffraction pattern with and without disc defocus in the recording process.

Fig. 1 shows the theoretical model of the collinear holographic data storage with disc defocus in the recording process. The quantity of disc defocus is z_r in the recording process. In the reading process, the quantity of disc defocus is z_d as shown in Fig. 2. Based on VOHIL theory [6] and scalar diffraction theory [7], we could derive the diffraction formula with disc defocus, which can be expressed by

$$D(x_0,y_0,a,b)=\int_{-T}^{T}\left\{\begin{array}{l}-(\lambda f)^2 e^{jk(4f+2z_d)} e^{-j\frac{\pi(z_d+\Delta z)}{\lambda f^2}(x_0^2+y_0^2)}\cdot\left[e^{-j\frac{2\pi}{\lambda f}(ax_0+by_0)}U_S(-x_0,-y_0)\cdot e^{j\frac{\pi(-z_r+\Delta z)}{\lambda f^2}(x_0^2+y_0^2)}\right] \\ \otimes\left[e^{-j\frac{2\pi}{\lambda f}(ax_0+by_0)}U_R^*(x_0,y_0)\cdot e^{-j\frac{\pi(-z_r+\Delta z)}{\lambda f^2}(x_0^2+y_0^2)}\right]\otimes\left[U_P(-x_0,-y_0)\cdot e^{j\frac{\pi(-z_d+\Delta z)}{\lambda f^2}(x_0^2+y_0^2)}\right]\end{array}\right\}d\Delta z\,. \quad (1)$$

Where U_S, U_R, and U_P are signal beam, reference beam, and reading beam, respectively.

3. Simulation results

Fig.3 shows the simulation results of the shift selectivity along x-direction with 360 μm disc defocus in the different random binary phase modulation. In the figure, "2 pixels" means that the pixel size of phase modulation is equal to 2 pixels of the intensity modulation. The width of half FWHM is between 0.23 and 1.05 μm. Fig. 4 shows the simulation results of the shift tolerance along z-direction with 360 μm disc defocus in the different random binary phase modulation. In the figure, the curve of the shift tolerance becomes asymmetrical with disc defocus. The width of half FWHM of the shift tolerance along z-direction is between 6.52 and 6.97 μm.

Fig. 5 is the simulation result of the diffraction pattern without disc defocus, and Fig. 6 is that with 360 μm disc defocus in the recording process. Comparing the two simulation results, the diffraction pattern with 360 μm disc defocus is clearer than that without disc defocus. Finally, the BER and SNR of the diffraction without disc defocus are 9.3×10^{-3} and 2.94, and that with 360 μm are 8.67×10^{-5} and 4.53, respectively.

4. Conclusion

We derive the diffraction formula of collinear holographic data storage with disc defocus in the recording and reading process. Then we simulate the shift selectivity along x-direction and the shift tolerance along z-direction with disc defocus. Finally, we simulate the diffraction pattern with and without disc defocus in the recording process. According to the simulation results, the quality of the diffraction with 360 μm disc defocus is superior to that without disc defocus.

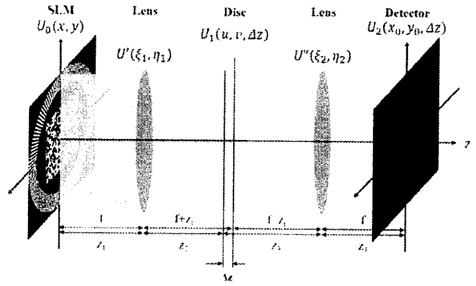

Fig. 1 The theoretical model in the recording process with disc defocus.

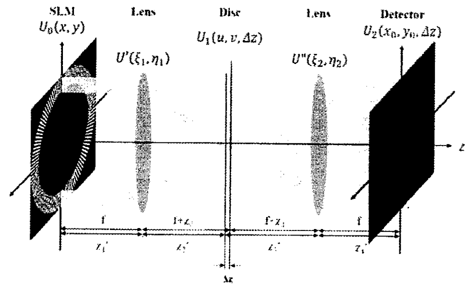

Fig. 2 The theoretical model in the reading process with disc defocus.

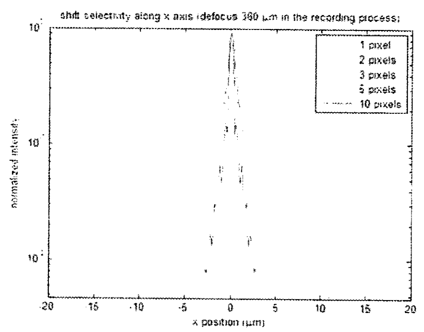

Fig. 3 Shift selectivity along x-direction with different random binary phase modulation.

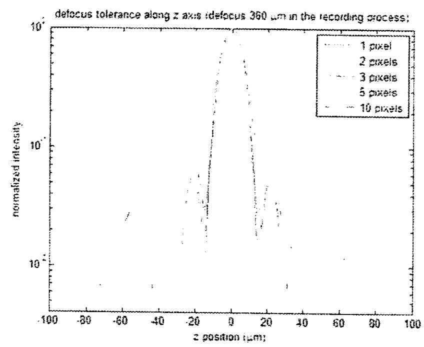

Fig. 4 Shift tolerance along z-direction with different random binary phase modulation.

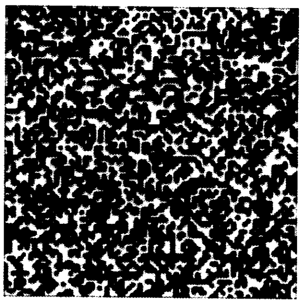

Fig. 5 The diffraction pattern without disc defocus.

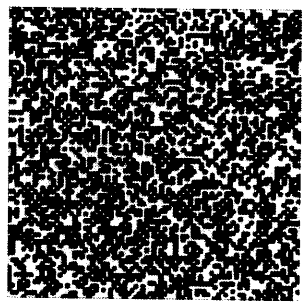

Fig.6 The diffraction pattern with 360 μm disc defocus.

Acknowledgement

This study was sponsored by the Ministry of Science and Technology of the Republic of China under grant MOST 104-2221-E-008-078-MY3.

Reference

[1] H. Horimai, X. Tan, and J. Li, "Collinear holography," Appl. Opt. **44**, 2575-2579 (2005).

[2] K. Curtis, A. Pu, and D. Psaltis, "Method for holographic storage using peristrophic multiplexing," Opt. Lett. **19**, 993-994 (1994).

[3] K. Anderson, and K. Curtis, "Ploytopic multiplexing," Opt. Lett. **29**, 1402-1404 (2004).

[4] Akio Yamakawa, Masahiro Saito, Tamotsu Yamagami, and Kenjiro Watanabe, "New Concept of Coaxial Holographic Recording," IWHM & D 2009 Digests, 3B-2 (2009).

[5] Kenji Tanaka, Masaaki Hara, Kazutatsu Tokuyama, Kazuyuki Hirooka, Koji Ishioka, Atsushi Fukumoto, and Kenjiro Watanabe, "Improved performance in coaxial holographic data recording," Opt. Express **15**, 16196-16209 (2007).

[6] C. C. Sun, "Simplified model for diffraction analysis of volume holograms," Opt. Eng. **42**, 1184-1185 (2003).

[7] J. W. Goodman, *Introduction to Fourier Optics*, 2nd eds. (McGraw-Hill, New York, 2002).

Scattering Suppression by Digital Optical Phase Conjugator

Yeh-Wei Yu, Ching-Cherng Sun*, Wei-Hsin Chen, Chih-Shun Ho, Szu-Yu Chen, and Che-Chu-Lin
Department of Optics and Photonics, National Central University, Taoyuan City 32001, Taiwan

Summary

For a holographic storage system with photopolymer used as recording material, the scattering noise usually sets the bottle neck of the storage capacity. In the reading process, the diffracted signal should be 10 times higher than the scattering noise [1]. Therefore, the scattering suppression is an important topic for holographic storage. Optical phase conjugation (OPC) is one of the most effective technique in the field of scattering suppression [2,3]. However, OPC based on nonlinear optics is always limited on sensitivity and efficiency. Besides, the requirement of specific wavelength and lack of stability make OPC not easy to be utilized. Digital optical phase conjugator (DOPC) is thus proposed to perform high light sensitivity, high stability and wide wavelength fidelity [4].

Figure 1 shows DOPC uses an interferometer and CMOS image sensor (CMOS-IS) to acquire the optical field distribution of the signal, and the phase-only spatial light modulator (pSLM) to produce the conjugate signal. To obtain a high-fidelity phase conjugate wave, the alignment between the image sensor and the spatial light modulator is critical. In this paper, we propose and demonstrate a novel way to align the pSLM and the CMOS-IS with the aid of a Kitty-type self-pumped phase conjugator (Kitty-SPPCM), which reflects phase conjugate wave in high speed and high sensitivity. The Kitty-SPPCM is used to make 6-dimensional alignment and phase compensation to reduce possible phase error.

The Kitty-SPPCM is proposed and demonstrated to generate a fast conjugate wave with high phase fidelity. Before the Kitty-SPPCM is formed, a Cat-SPPCM must be built up in a photorefractive crystal. Then another part of the laser reflected by the polarized beam splitter (PBS) is incident on the pSLM to carry a special-design image (Fig. 2). The reflected light is directed into the $BaTiO_3$ crystal. The incident signal beam from the other side of the crystal must passthrough the fanning loop of the Cat-SPPCM. Then the Kitty-SPPCM is formed and a phase conjugate wave can be observed in the plane of COMS-IS. A special design pattern is used to align the lateral position and the in-plane rotation between the pSLM and the CMOS-IS. In order to extend the accepted incidence area and angle of the Kitty-SPPCM, we starts from changing the incidence position from the other three faces in the incident plane. The incident direction along or in the counter-direction with respect to the c axis cannot form the Kitty-SPPCM effectively. It is because the coupling strength of the grating for the four-wave mixing with the fanning loop is too weak. When the incident light is sent into the crystal in the counter-direction of the master light for the Cat-SPPCM, an effective Kitty-SPPCM can be observed. According to the forming of the Kitty-SPPCM, the incidence position can be divided into three regions, as shown in Fig. 3. The images carried by the phase conjugate waves from the three regions are shown in Fig. 4. A high-quality Kitty-SPPCM can be formed in Region A with a counter-direction incidence with respect to the master light for the Cat-SPPCM. In addition, the incidence position located in region B can form a Kitty-SPPCM with in-plane high-pass filtering. Furthermore, a SPPCM similar to the Bridge-SPPCM is found in region C, but with longer forming time rather than normal Kitty-SPPCM. The discovery of these three kinds of OPC extends the accepted incidence position range, which is helpful in applying the SPPCM to DOPC alignment.

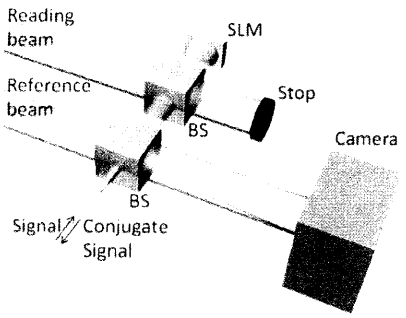

Fig. 1 The schematic diagram of DOPC.

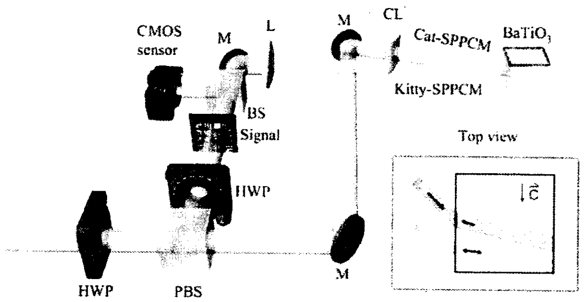

Fig. 2 The schematic diagram of a Kitty-SPPCM.

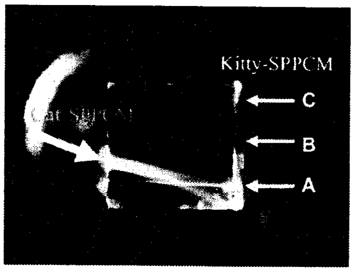

Fig. 3 The SPPCM with counter-direction incidence can be divided into three regions.

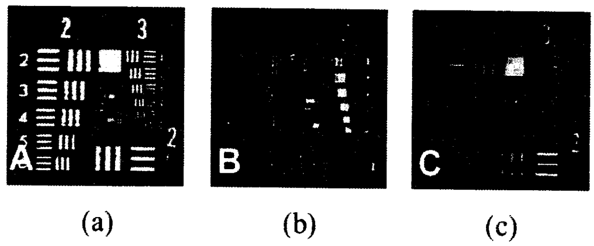

Fig. 4 The phase conjugate images in the three regions. (a) Image in region A, (b) in region B, and (c) in region C.

References

1) K. Curtis, L. Dhar, A. Hill, W. Wilson, and M. Ayres, *Holographic Data Storage: From Theory to Practical Systems* (Wiley, 2010).
2) A. Yariv, and P. Yeh, "Phase conjugate optics and real-time holography," IEEE J. Quantum Electron. **14**, 650–660 (1978).
3) J. Feinberg, and R. W. Hellwarth, "Phase-conjugating mirror with continuous-wave gain," Opt. Lett. **5**, 519– 521 (1980).
4) Meng Cui and Changhuei Yang, "Implementation of a digital optical phase conjugation system and its application to study the robustness of turbidity suppression by phase conjugation," Opt. Express **18**, 3444-3455 (2010).