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(please insert ref. above)

The Research Grants Council of Hong Kong
NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title

Key technology in time-reversal based optical scanning holography and its application on fluorescent biological specimens

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof. Edmund Lam	Prof. Bingzhong Wang
Post	Professor	Professor
Unit / Department / Institution	Department of Electrical and Electronic Engineering / The University of Hong Kong	School of Physical Electronics / University of Electronic Science and Technology of China
Contact Information	elam@eee.hku.hk	bzwang@uestc.edu.cn
Co-investigator(s) *(with title and institution)*		Dr. Haiyan Ou, Associate Professor, University of Electronic Science and Technology of China

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1/1/2014		
Project Completion date	31/12/2017		
Duration *(in month)*	48		
Deadline for Submission of Completion Report	31/12/2018		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. To advance the system architecture in OSH based on the time-reversal technique. We focus in particular on designing the optical transfer function (OTF) of the OSH system. The aim is to create an optimal scattered OTF to achieve the super-resolution with time reversal technique.

2. To advance the scanning mechanism and image reconstruction method in OSH based on time-reversal technique. This includes optical hardware modification, mathematical algorithms development, and software implementation.

3. To apply the time-reversal based OSH on fluorescent biological specimens. The aim is to demonstrate practical uses of the time-reversal based OSH.

5.2 Revised Objectives

Date of approval from the RGC: _____

Reasons for the change: _____

_____

1.
2.
3. ....

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

Through this project, we have made significant advancements concerning optical scanning holography. A major aspect of the research outcome relates to the algorithms and systems improvement for better imaging capabilities. These include:

- Defocus noise suppression
- Axial localization and resolution enhancement
- Lateral resolution enhancement
- Extended focused imaging
- Depth map generation
- Fast, non-adaptive imaging
- Compressive holographic imaging
- Autofocusing
- Edge extraction

Information concerning how these relate to the publications given in Part C has been discussed in 5.3 above.

Another aspect of the research outcome pertains to the application of the improved optical scanning holography technology. In many of the publications concerning algorithms and systems development, we have also shown the applicability of the technology through various experiments. In particular, we would like to highlight the development of subsampled scanning holographic imaging (SuSHI), which is published in the high impact journal Optica. It addresses a key technical challenge in fluorescent imaging involving a long scan time: prolonged laser scanning can cause damage to the

specimen. Our solution comes in the form of computational imaging, where we adjust the hardware to scan in a spiral trajectory, and we make use of compressed sensing in image reconstruction. The net result is that we can capture as little as 4% of the full data – representing a 25-times speed-up – while maintaining the image quality.

Potential for further development of the research and the proposed course of action *(maximum half a page)*

This project has resulted in a number of peer-reviewed journal publications and conference presentations, which together help push the technology and application of optical scanning holography for biomedical imaging. A number of directions are possible for further development. The first one concerns the SuSHI technology, where further research on adaptive scanning and multiple spiral patterns may lead to continuous imaging speed improvement and artifact suppression, eventually leading to real-time monitoring and tracking of dynamic specimens. A second direction is on improving image resolution. Recently, data-driven approaches involving machine learning have demonstrated dramatic results in many domains, and while some research groups have started to experiment with such methods for holographic imaging, there is much room to make use of the approach for resolution enhancement. A third direction is on capturing multispectral information. So far, the holograms and the reconstructed images are grayscale, but it is technically possible to enhance the system to capture the data at multiple wavelengths, leading to multispectral optical scanning holography, which may lead to new applications.

7. The Layman's Summary

(describe <u>in layman's language</u> the nature, significance and value of the research project, in no more than 200 words)

Different forms of optical imaging allow us to capture information about the world we live in, and holographic imaging in particular makes it possible to retain three-dimensional information. Optical scanning holography is one such technique, and is particularly powerful in imaging biological specimens that involve staining with fluorescent dyes. In this project, we have made several advances to the optical hardware and the software algorithms that significantly enhance the capability of this scanning holographic system, such as improving the image quality through noise suppression, better resolution in both axial and lateral directions, and faster imaging. These are achieved through a methodology known as computational optical imaging, where computational algorithms complement the optical system design in capturing information from the object and reconstructing such information for better visual quality. Consequently, such improvement in imaging capability is shown in the imaging of fluorescent specimens, where the benefit of faster scanning makes it possible to avoid damages to the object while allowing good image quality for our observations, in turn contributing to the advancement of life science as we can obtain more information about the specimens.

Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) *(**bold** the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	Title and Journal/ Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*						
2015				**Haiyan Ou***, Huiyu Pan, **Edmund Y. Lam**, and **Bing-Zhong Wang**	"Defocus noise suppression with combined frame difference and connected component methods in optical scanning holography," Optics Letters, vol. 40, no. 17, 4146–4149, September 2015.	Yes (2015)	No	Yes	Yes

2015				Antony C.S. Chan, Andy K.S. Lau, Kenneth K.Y. Wong, **Edmund Y. Lam**, and Kevin K. Tsia*	"Arbitrary two-dimensional spectrally encoded pattern generation—a new strategy for high-speed patterned illumination imaging," Optica, vol. 2, no. 12, pp. 1037–1044, December 2015.	Yes (2015)	No	Yes	Yes
2016				Ni Chen, Zhenbo Ren, **Haiyan Ou**, and **Edmund Y. Lam***	"Resolution enhancement of optical scanning holography with a spiral modulated point spread function," Photonics Research, vol. 4, no. 1, pp. 1–6, February 2016.	No	Yes	Yes	Yes

2016				Zhenbo Ren, Ni Chen, and **Edmund Y. Lam***	"Extended focused imaging and depth map reconstruction in optical scanning holography," Applied Optics, vol. 55, no. 5, pp. 1040–1047, February 2016.	No	Yes	Yes	Yes
2016				Ni Chen, Zhenbo Ren, and **Edmund Y. Lam***	"High-resolution Fourier hologram synthesis from photographic images through computing the light field," Applied Optics, vol. 55, no. 7, pp. 1751–1756, March 2016.	No	Yes	Yes	Yes

2016				Antony C.S. Chan, Kevin K. Tsia, and **Edmund Y. Lam***	"Subsampled scanning holographic imaging (SuSHI) for fast, non-adaptive recording of three-dimensional objects," Optica, vol. 3, no. 8, pp. 911–917, August 2016.	No	Yes	Yes	Yes
2017				Antony C.S. Chan, Ho-Cheung Ng, Sharat C.V. Bogaraju, Hayden K.-H. So, **Edmund Y. Lam**, and Kevin K. Tsia*	"All-passive pixel super-resolution of time-stretch imaging," Scientific Reports, vol. 7, pp. 44608, March 2017.	No	Yes	Yes	Yes
2017				Ni Chen*, Zhenbo Ren, Dayan Li, **Edmund Y. Lam**, and Guohai Situ	"Analysis of the noise in backprojection light field acquisition and its optimization," Applied Optics, vol. 56, no. 13, pp. F20–F26, May 2017.	No	Yes	Yes	Yes

2017				Zhenbo Ren, Ni Chen, and **Edmund Y. Lam***	"Automatic focusing for multisectional objects in digital holography using the structure tensor," Optics Letters, vol. 42, no. 9, pp. 1720–1723, May 2017.	No	Yes	Yes	Yes
2018				**Haiyan Ou***, Yong Wu, **Edmund Y. Lam**, **Bing-Zhong Wang**	"Axial localization using time reversal multiple signal classification in optical scanning holography," Optics Express, vol. 26, no. 4, pp. 3756-3771, Feb 2018.	No	Yes	Yes	Yes

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered

(Please attach a copy of each delivered paper. All listed papers must acknowledge RGC's funding support by quoting the specific grant reference.)

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*

July/2014/Seattle	High-resolution section recovery using a configurable pupil in a scanning holographic microscopy	OSA Topical Meeting in Signal Recovery and Synthesis	Yes (2015)	No	Yes	Yes
July/2014/Seattle	Reducing the acquisition time of optical scanning holography by compressed sensing	OSA Topical Meeting in Signal Recovery and Synthesis	Yes (2015)	No	Yes	Yes
July/2014/Seattle	Computational sectioning and resolution enhancement in optical scanning holography	OSA Topical Meeting in Digital Holography and Three-Dimensional Imaging	Yes (2015)	No	Yes	Yes
September/2014/Sapporo	Efficient autofocusing in optical scanning holography	The Japan Society of Applied Physics and The Optical Society Joint Symposia	Yes (2015)	No	Yes	Yes
October/2014/Beijing	Signal reduction in fluorescence imaging using radio frequency-multiplexed excitation by compressed sensing	SPIE Real-time Photonic Measurements, Data Management, and Processing	Yes (2015)	No	Yes	Yes
May/2015/Shanghai	Autofocusing of optical scanning holography based on entropy minimization	OSA Topical Meeting in Digital Holography and Three-Dimensional Imaging	Yes (2015)	No	Yes	Yes
May/2015/Shanghai	Depth enhancement of optical scanning holography with a spiral phase plate	OSA Topical Meeting in Digital Holography and Three-Dimensional Imaging	Yes (2015)	No	Yes	Yes
May/2015/Shanghai	Edge extraction based on aperture synthesis in optical scanning holography	OSA Topical Meeting in Digital Holography and Three-Dimensional Imaging	Yes (2015)	No	Yes	Yes
September/2015/Macau	Extended focused imaging in a holographic microscopy imaging system	IEEE International Conference on Imaging Systems and Techniques	Yes (2015)	No	Yes	Yes

February/2016/San Francisco	Pixel super-resolution of time-stretch imaging by an equivalent-time sampling concept	SPIE High-Speed Biomedical Imaging and Spectroscopy: Toward Big Data Instrumentation and Management	No	Yes	Yes	Yes
October/2016/Beijing	Super-resolution imaging in optical scanning holography using structured illumination	SPIE Holography, Diffractive Optics, and Applications	No	Yes	Yes	Yes
May/2017/Nagoya	Computational single-cell classification using deep learning on bright-field and phase images	IAPR Conference on Machine Vision Applications	No	Yes	Yes	Yes
May/2017/Jeju Island	Edge-preserving autofocusing in digital holography	OSA Topical Meeting in Digital Holography and Three-Dimensional Imaging	No	Yes	Yes	Yes
May/2017/Jeju Island	Enhanced edge extraction using spiral phase plate in optical scanning holography based on gaussian beam apodization	OSA Topical Meeting in Digital Holography and Three-Dimensional Imaging	No	Yes	Yes	Yes
August/2017/Tokyo	Image super-resolution for ultrafast optical time-stretch imaging	24th Congress of the International Commission for Optics	No	Yes	Yes	Yes

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
CHAN Chi Shing Antony	PhD	September 2012 – August 2016	August 2016
REN Zhenbo	PhD	September 2014 – August 2018	August 2018

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

This project has enabled collaboration with Dr. Ni Chen, currently a visiting scholar at Seoul National University, on leave from the Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Science.