Incoherent digital holography for multidimensional motion-picture imaging

Tatsuki Tahara[1], Yuichi Kozawa[2], Tomoya Nakamura[3], Atsushi Matsuda[4], and Tomoyoshi Shimobaba[5]

[1] Applied Electromagnetic Research Center, Radio Research Institute, National Institute of Information and Communications Technology (NICT)

[2] Institute of Multidisciplinary Research for Advanced Materials, Tohoku University

[3] SANKEN, Osaka University

[4] Advanced ICT Research Institute Kobe, National Institute of Information and Communications Technology (NICT)

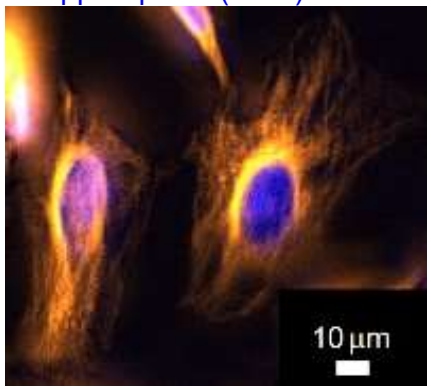
[5] Graduate School of Engineering, Chiba University

Research topics of our group in incoherent digital holography (IDH)

IDH: Technique for recording a digital hologram of spatially and temporally incoherent light and obtaining a 3D image of incoherent light from the recorded hologram

3D fluorescence microscopy

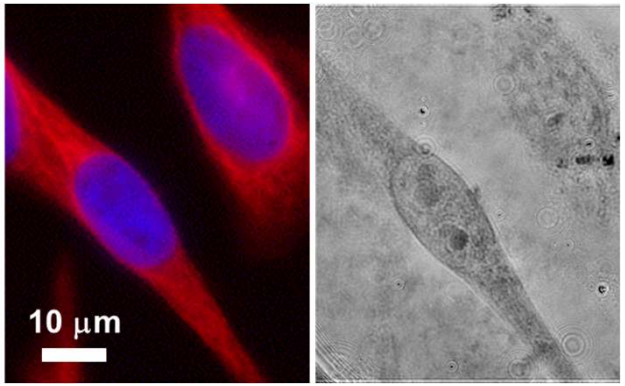
Appl. Opt. **60** (2021) A260.



Multimodal imaging

Opt. Express **30** (2022) 1182.

Fluorescence Phase



Portable hologram recorders

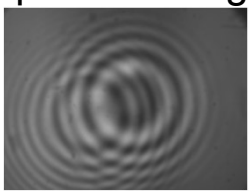
Holosensor, Holocamera

OSA Continuum **4** (2021) 2372, Opt. Express **30** (2022) 21582, 3DC2022.

Identification of the varieties of light

Opt. Express **30** (2022) 21582.

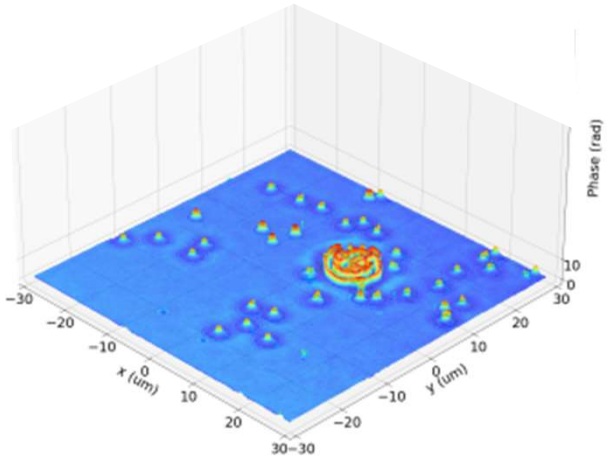
Multiplexed hologram



LED Fluorescence

Quantitative phase motion-picture imaging

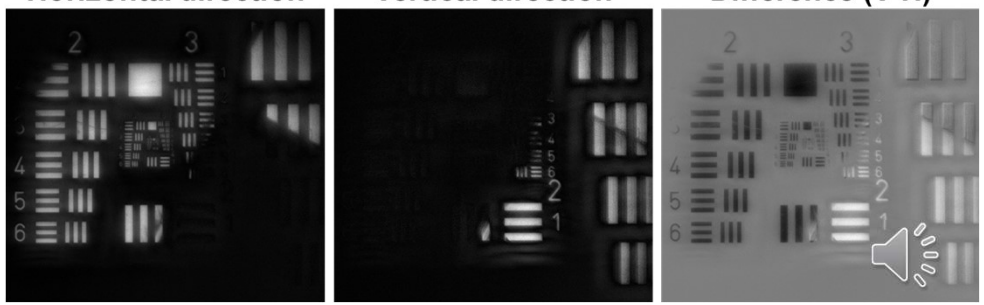
Opt. Express **30** (2022) 1182.



Filterless polarization 3D imaging

T. Tahara, BISC2022.

Horizontal direction Vertical direction Difference (V-H)



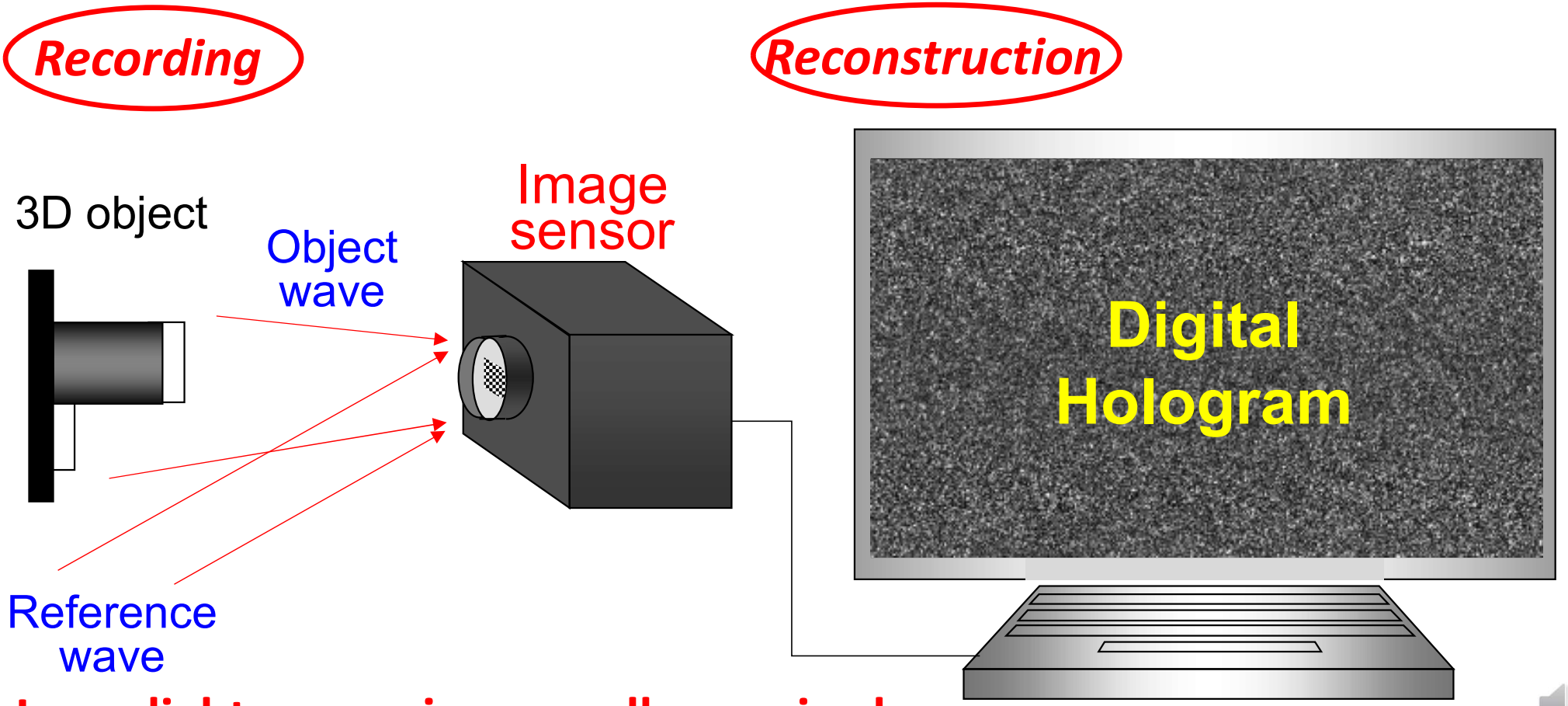
3D motion-picture imaging of multiple 210-nm particles at more than 100 fps

Applied Physics B **128** (2022) 193.

Digital holography (DH)

J. Goodman, *Appl. Phys. Lett.* **11** (1967) 77.

- Recording:
  Interference fringe image (digital hologram) by an image sensor
- Reconstruction:
  Calculation of diffraction integrals to obtain 3D image in a computer



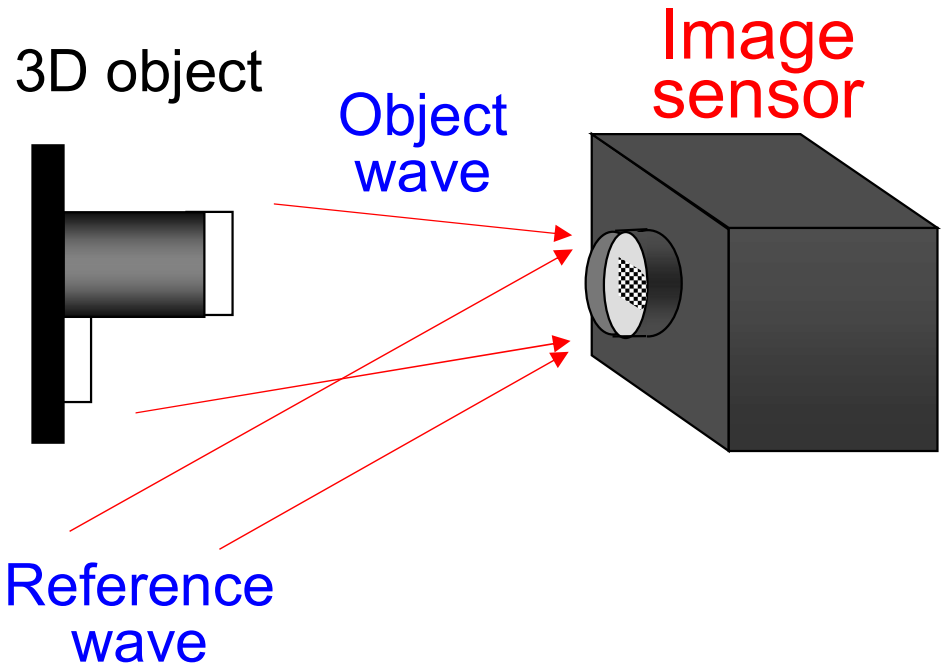
Laser light source is generally required.

Digital holography (DH)

J. Goodman, *Appl. Phys. Lett.* **11** (1967) 77.

- Recording:
  Interference fringe image (digital hologram) by an image sensor
- Reconstruction:
  Calculation of diffraction integrals to obtain 3D image in a computer

Recording



Reconstruction

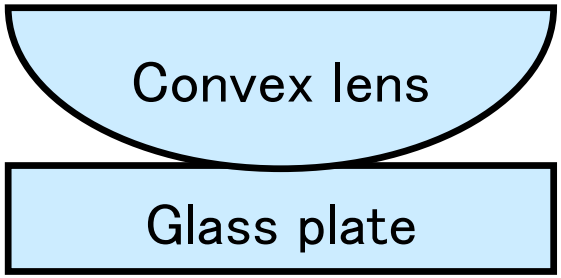
Laser light source is generally required. → Speckle-noise problem

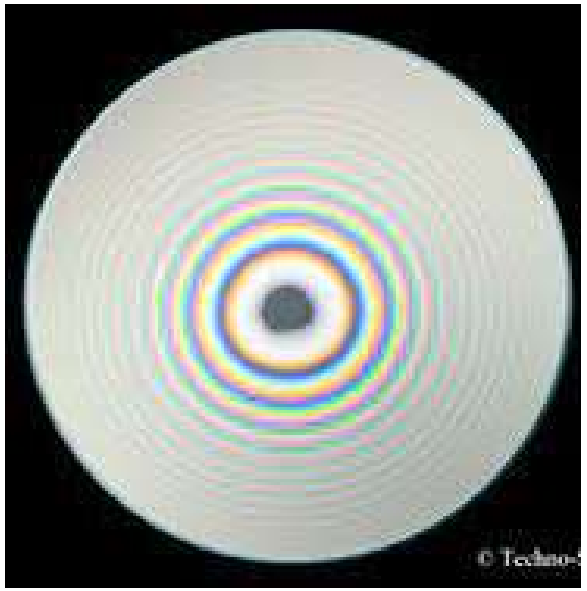
Interference fringe images generated with natural light

Interference fringe pattern on a babble soap

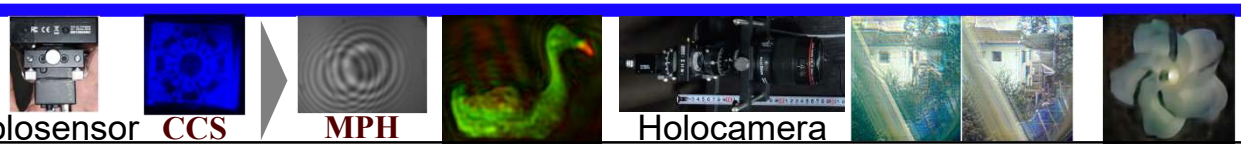
http://www.ccs-inc.co.jp/s2_ps/s1/s_04/column/light_color/vol22.html

Newton ring
(Gabor zone-plate pattern with white light)





Self-interference phenomena → Applied to digital holography as IDH



tahara@nict.go.jp

History and near future IDH

J. Rosen, *et al.*, *Adv. Opt. Photon.* **11** (2019) 1.
T. Tahara, *et al.*, *Appl. Phys. B* **128** (2022) 193.

1960's : Birth of incoherent holography

A. W. Lohmann, *J. Opt. Soc. Am.* **55** (1965) 1555.
P. J. Peters, *Appl. Phys. Lett.* **8** (1966) 209.

1970-90's : OSH, Phase-shifting IDH (Conoscopic holography)

T. C. Poon and A. Korpel, Opt. Lett. **4** (1979) 317.
T.-C. Poon Opt. Lett. **10** (1985) 197.
K. Itoh, *et al.*, Appl. Opt. **29** (1990) 1625.
G. Sirat and D. Psaltis, *Opt. Lett.* **10** (1985) 4.
L. M. Mugnier and G. Y. Sirat, *Opt. Lett.* **17** (1992) 294.

1990's : Holographic fluorescence microscopy (HFM) using OSH

B. W. Schilling, *et al.*, *Opt. Lett.* **22** (1997) 1506.

2000's : Various IDH techniques including FINCH*

K. Yoshimori, *J. Opt. Soc. Am. A* **18** (2001) 765.
M. Takeda, *et al.*, *Opt. Express* **13** (2005) 9629.
*J. Rosen and G. Brooker, *Opt. Lett.* **32** (2007) 912.

2010's : PSF improvement with FINCH, Single-shot imaging

J. Rosen, *et al.*, *Adv. Opt. Photon.* **11** (2019) 1.
(Including COACH and I-COACH)
T. Tahara, *et al.*, *J. Opt.* **19** (2017) 065705.

2020's : Many articles

- Multidimensional measurement
  (3D + Wavelength, Polarization, Phase)
- High-speed motion-picture measurement
- Compact & Applications
- Improvement of specifications with optical design

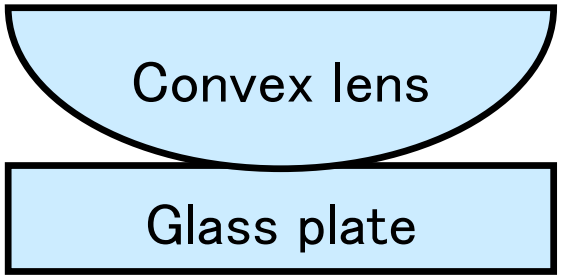
Time

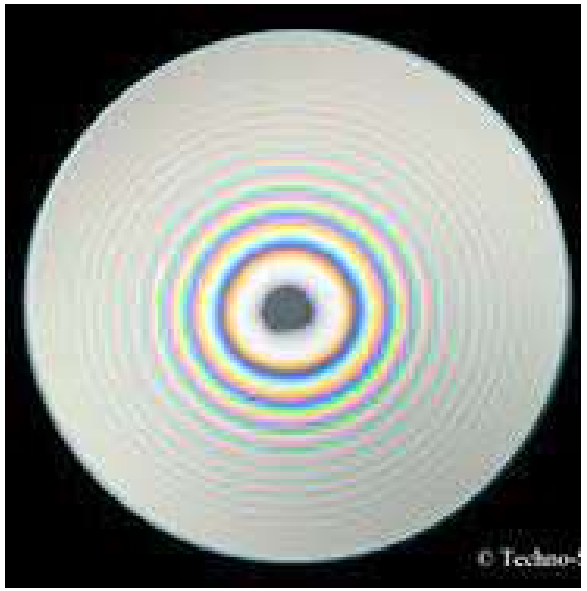
Interference fringe images generated with natural light

Interference fringe pattern
on a babble soap

http://www.ccs-inc.co.jp/s2_ps/s1/s_04/column/light_color/vol22.html

Newton ring
(Gabor zone-plate pattern
with white light)





Self-interference phenomena → Applied to digital holography as IDH

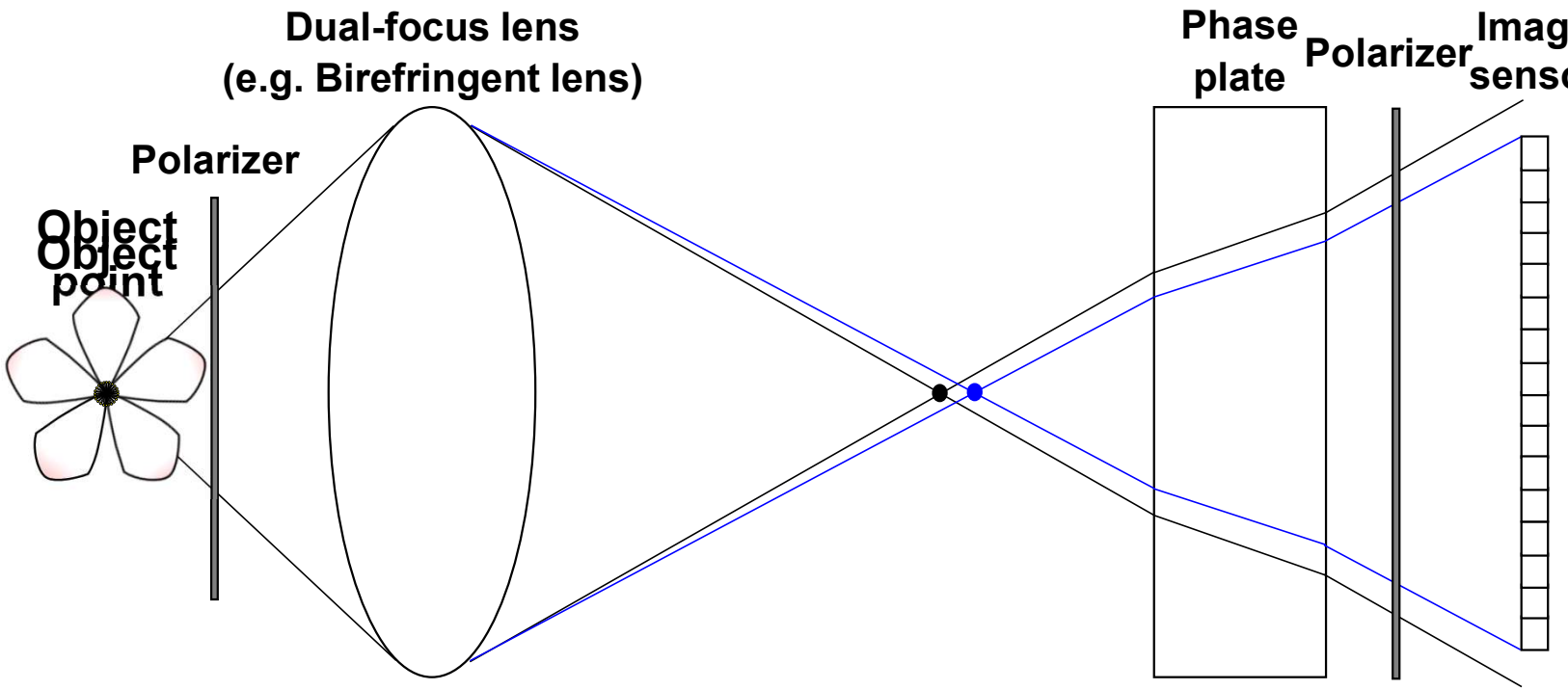
FINCH : attracts many researchers and sets a trend for IDH

COACH, I-COACH : connects IDH and coded aperture imaging and improves the specifications of FINCH

Our group : introduces many laser DH techniques to IDH and conducts multidimensional holographic imaging

Incoherent digital holography (IDH)

e.g. *Opt. Express* **30** (2022) 21582.



Hologram of an object point

Image reconstruction

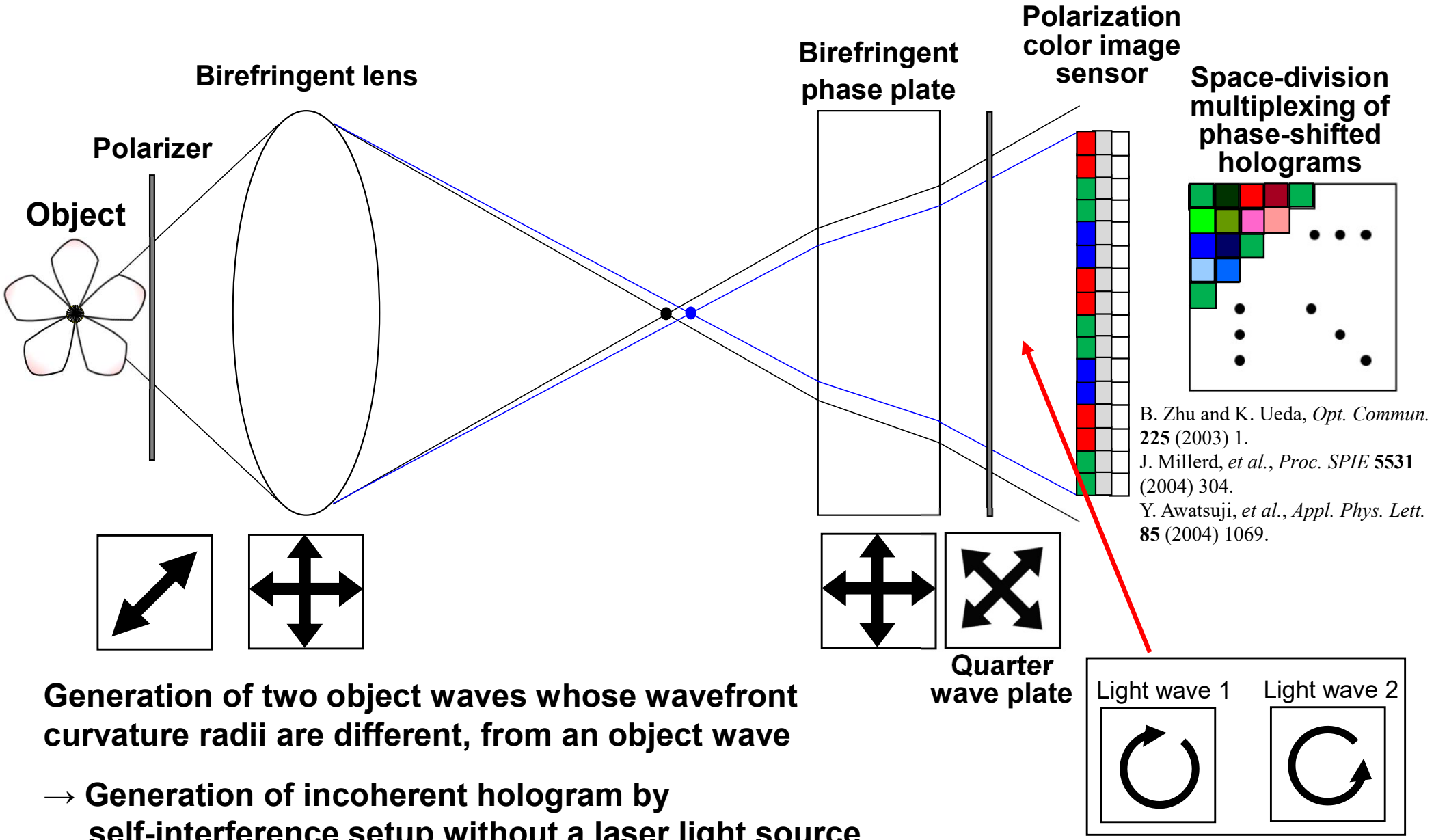
Generation of two object waves whose wavefront curvature radii are different, from an object wave

→ Generation of incoherent hologram by self-interference setup without a laser light source

Incoherent summation of holograms of multiple object points is regarded as an incoherent hologram of an object.

Object image can be reconstructed by directly applying an image-reconstruction algorithm of laser holography.

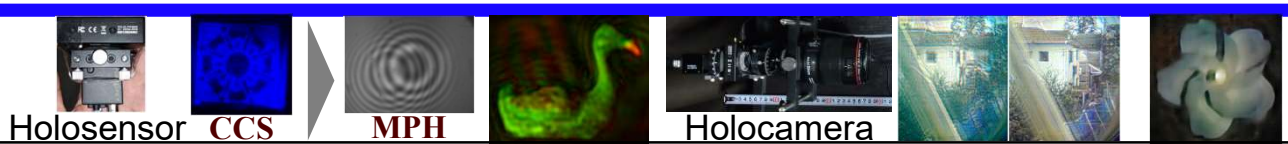
Single-shot full-color IDH with single-shot phase-shifting interferometry



B. Zhu and K. Ueda, *Opt. Commun.* **225** (2003) 1.
J. Millerd, *et al.*, *Proc. SPIE* **5531** (2004) 304.
Y. Awatsuji, *et al.*, *Appl. Phys. Lett.* **85** (2004) 1069.

Generation of two object waves whose wavefront curvature radii are different, from an object wave

→ Generation of incoherent hologram by self-interference setup without a laser light source

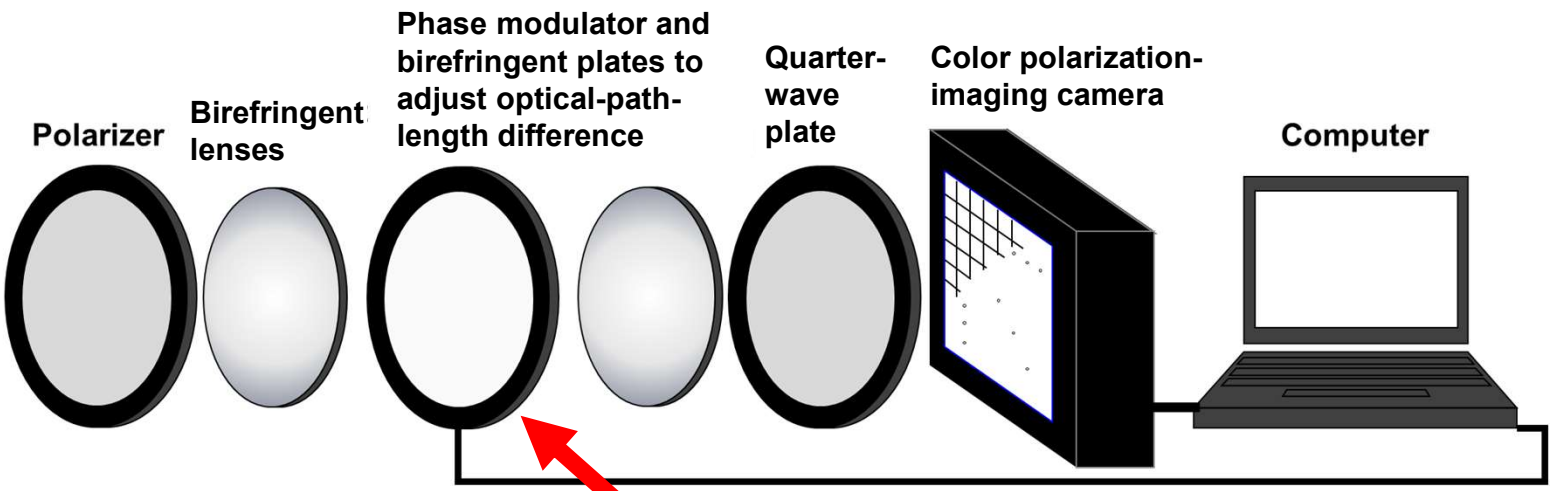


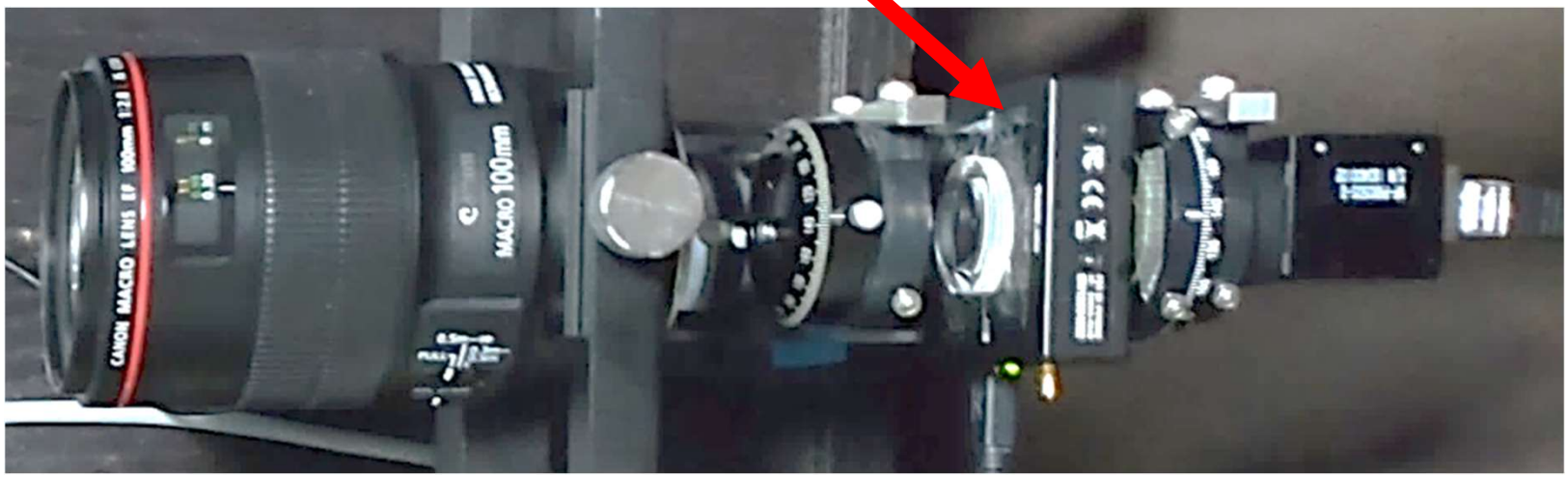
tahara@nict.go.jp

Portable single-shot full-color IDH system “Holocamera”

A camera lens to minify the object image

Single-shot phase-shifting incoherent color holography system using birefringent materials

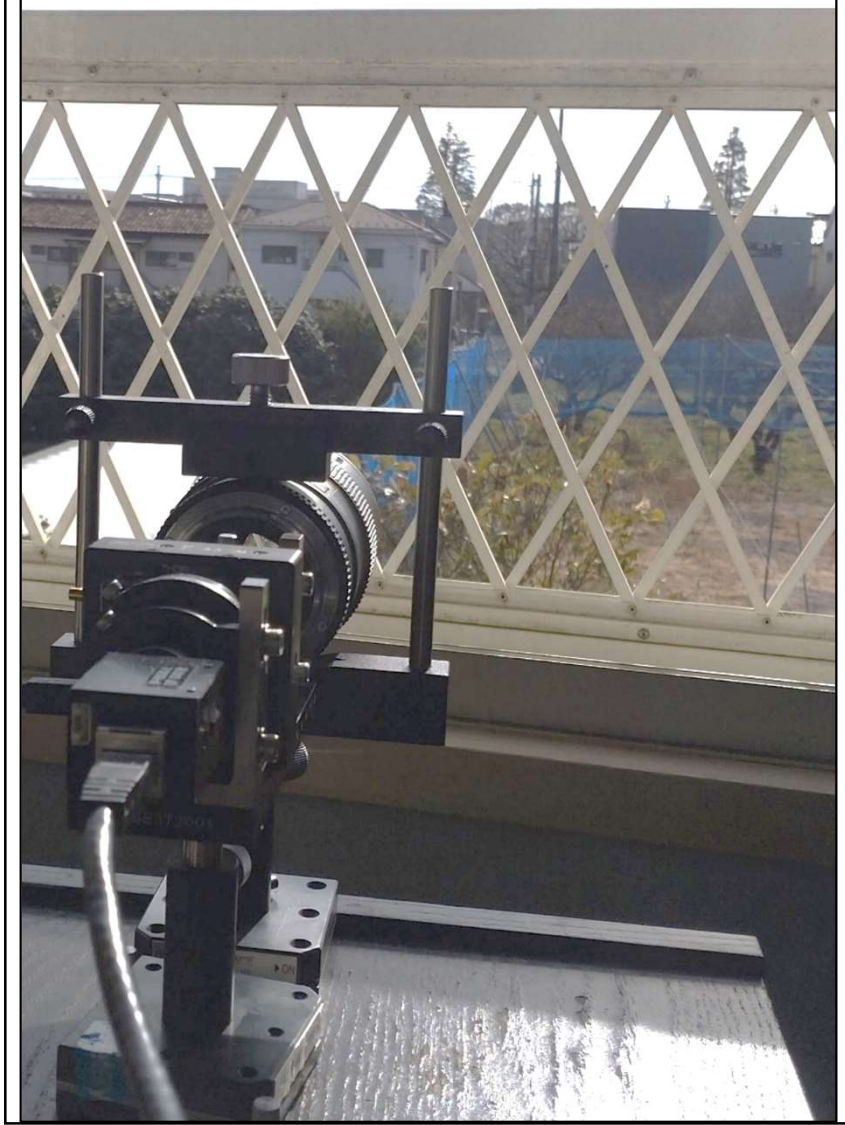




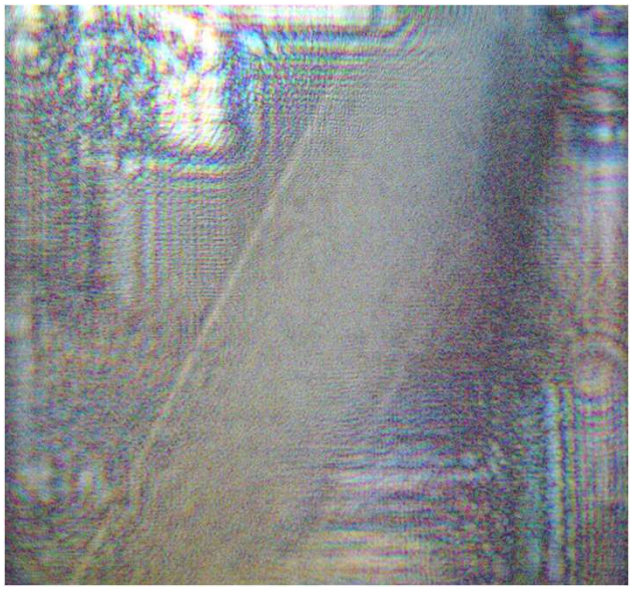
- A camera lens is introduced to record an incoherent hologram of large-size 3D objects.
- Careful adjustment of optical-path-length difference between light waves is achieved using a liquid crystal phase modulator.

Experiments using sunlight

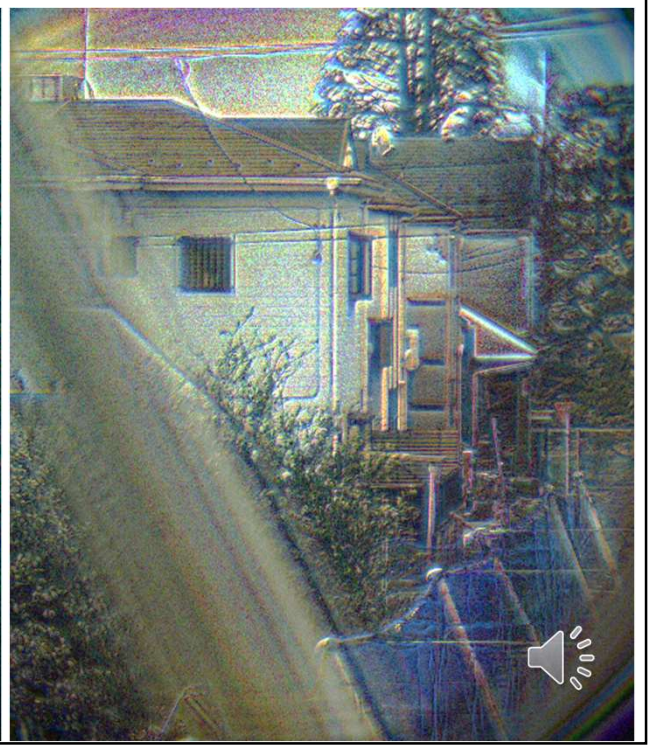
T. Tahara, *DH2022*.



Focused on metallic bar

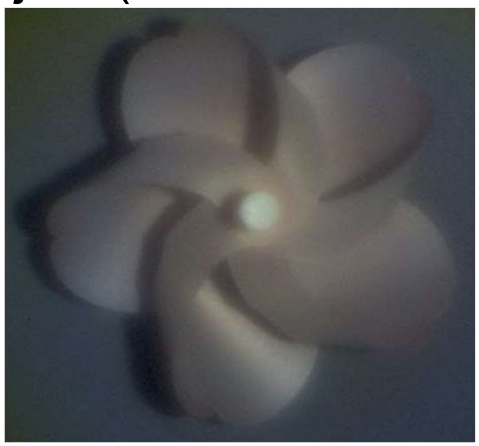


Focused on houses



Experiments using RGB-LED and moving objects

Object (30-mm diameter)



Rotator in the shape of a cherry blossom

- Thorlabs RGB-LED (LED4D201)
  625, 530, 455 [nm]
- Canon camera lens
  (EF100mm F2.8L Macro IS USM)
- Sony color polarization-imaging camera
  22 fps, 2448 x 2048 pixels, 8-bit depth
- Rotation of the object was recorded.

Recorded holograms

Reconstructed images

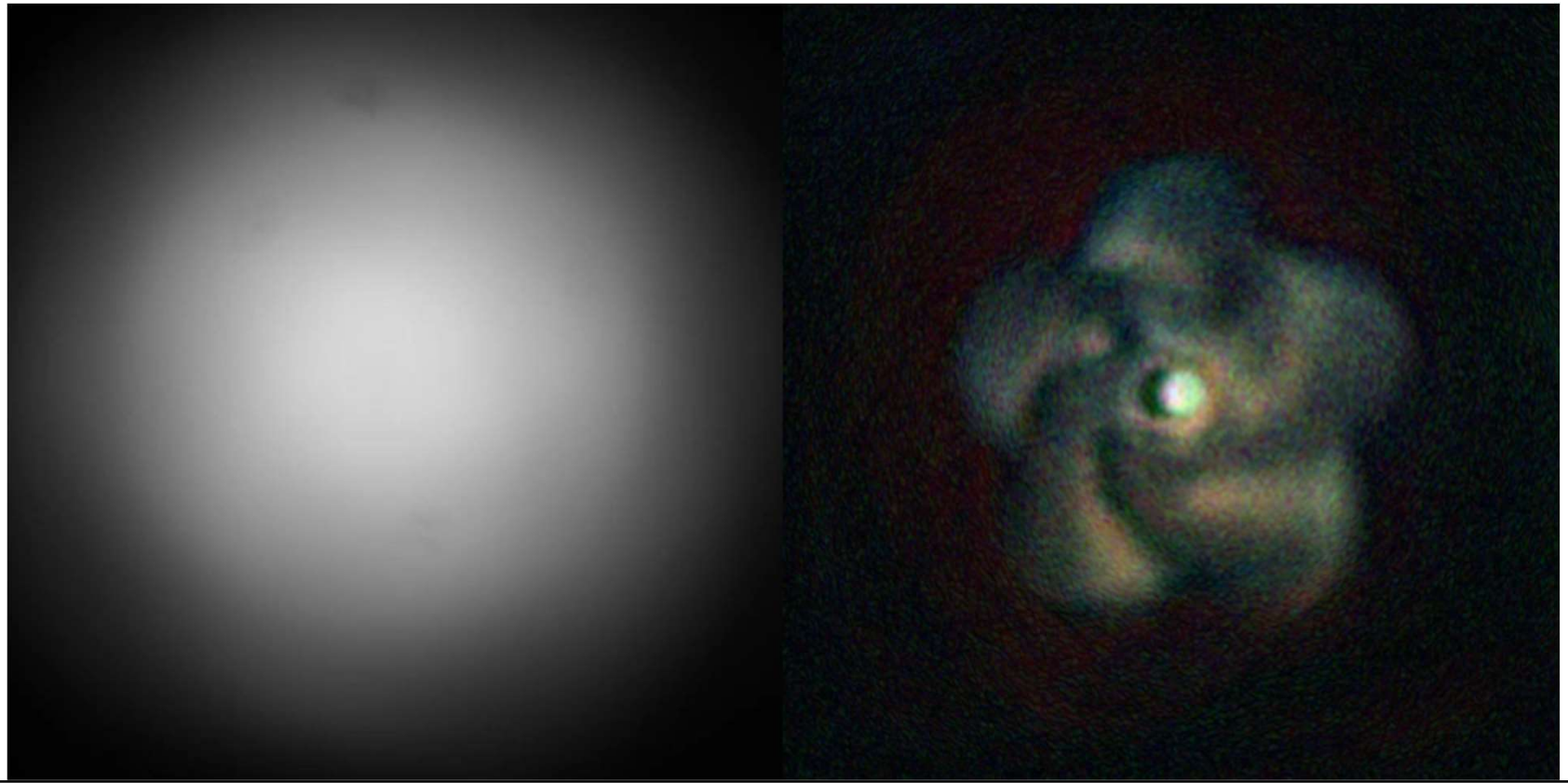
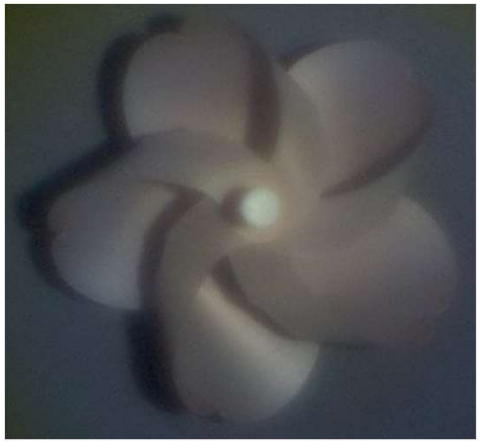
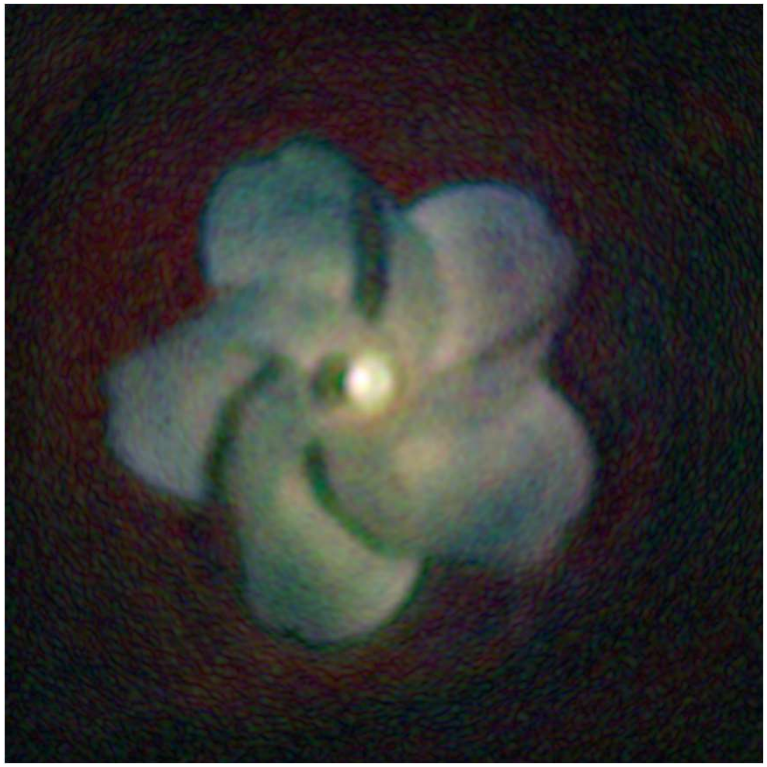


Image-quality improvement using a machine learning technique

Object



Before



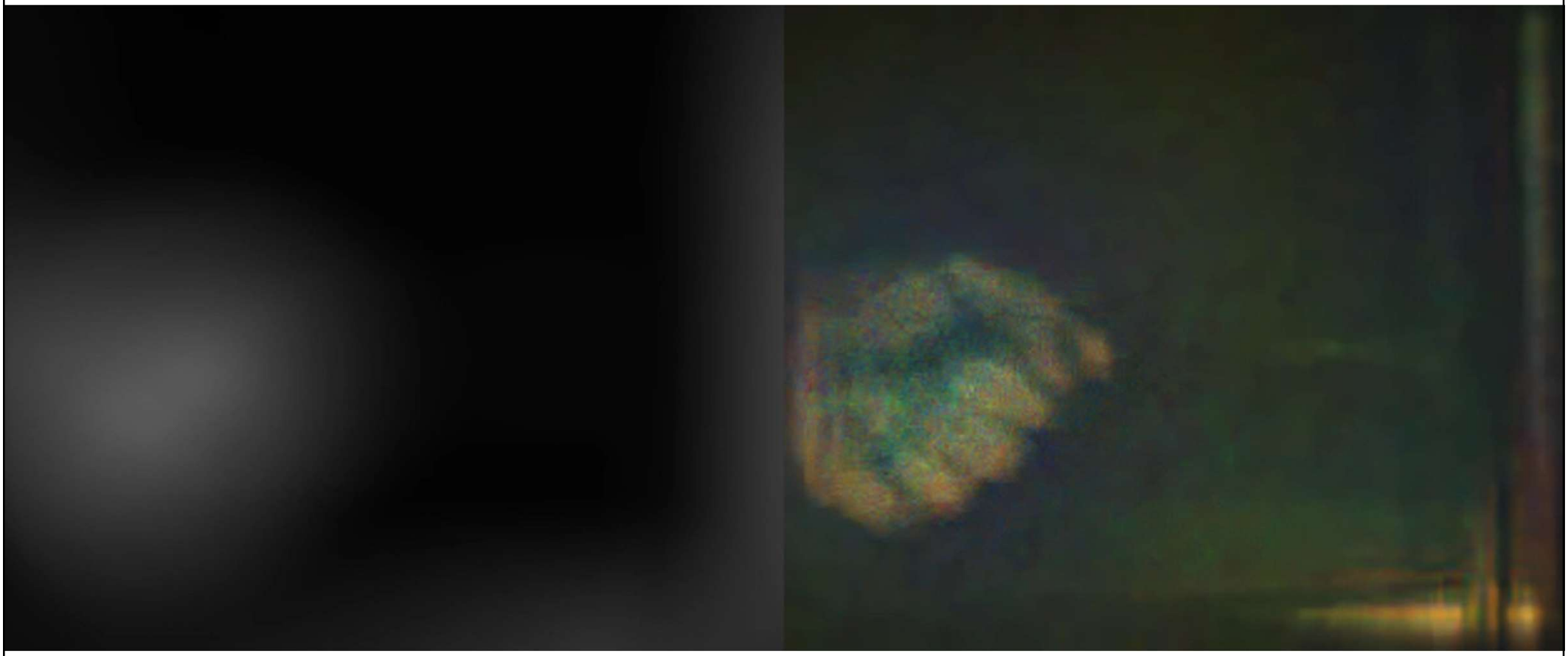
After (MIRNet)

Speckle-noiseless single-shot holographic imaging was achieved.

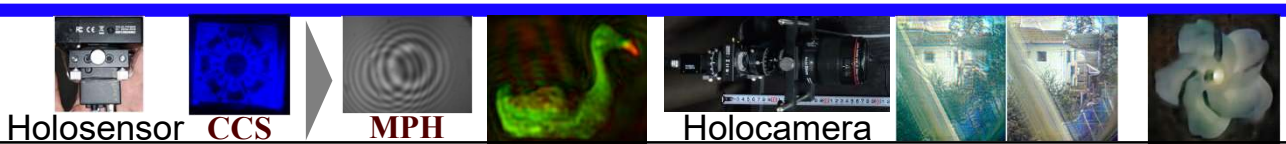
Experiments using RGB-LED and moving objects

Recorded holograms

Reconstructed images with BM4D technique



3D motion-picture imaging of a large object is successfully conducted because the BM4D technique efficiently suppresses the random noise.



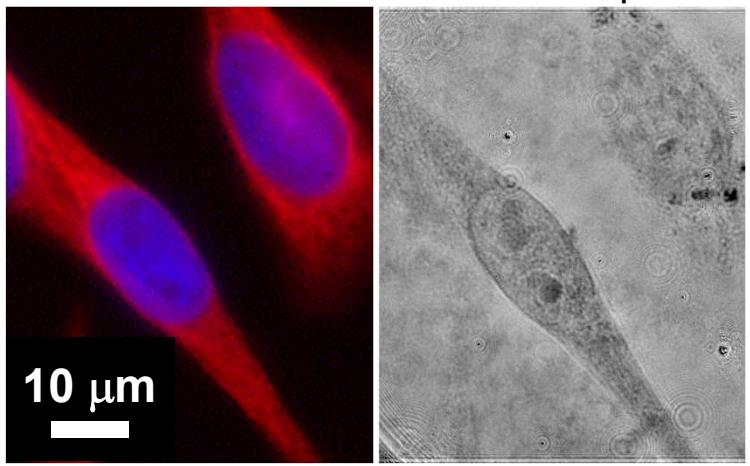
tahara@nict.go.jp

Research directions of DH with daily-use light

Label-free quantitative measurement of transparent specimens

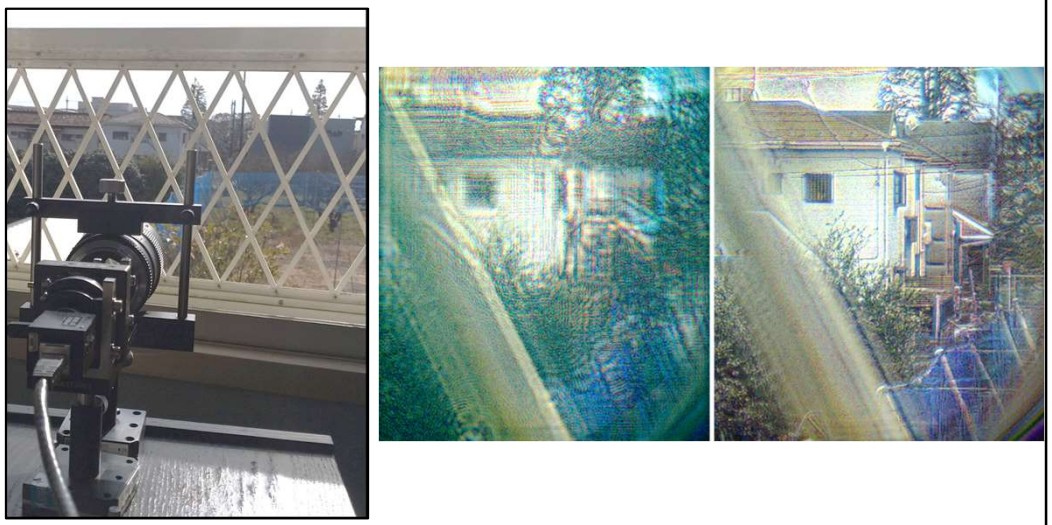
Opt. Express **30** (2022) 1182.

Fluorescence Quantitative phase



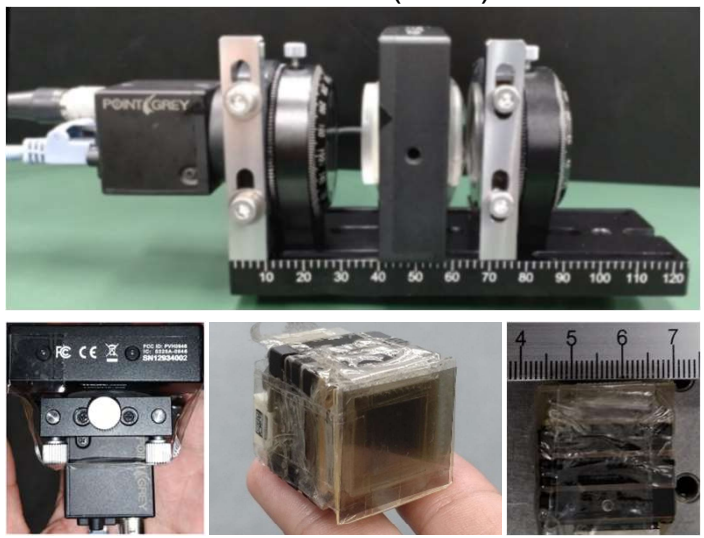
Holography with daily light

Recording of natural light as hologram



Compact hologram recorder - Holosensor -

Opt. Express **30** (2022) 21582.
OSA Continuum **4** (2021) 2372.



3D image-recording function to commercially available apparatus

Opt. Lett. **45** (2020) 2482. Appl. Phys. Lett. **117** (2020) 031102.
Appl. Opt. **60** (2021) A260.

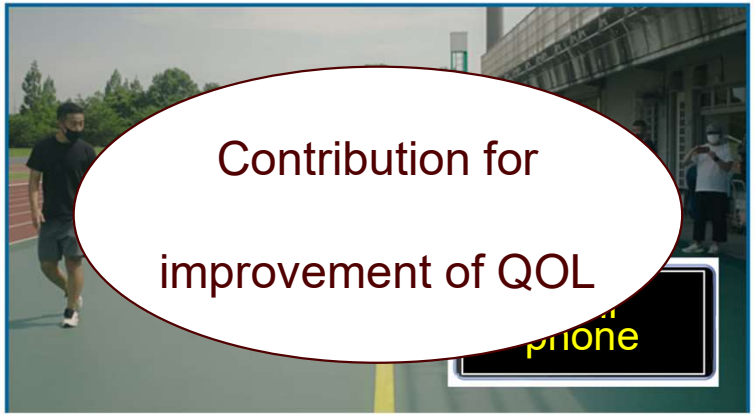
Contributions of holography for the future of our society

Measurement apparatus
(Camera, Telescope, Microscope)

Machine vision

Incoherent digital holography

Assistance of human walk with cellphone camera and AI



https://www.itmedia.co.jp/news/articles/2108/17/news103.html

Image acquisition for advancement of digital contents

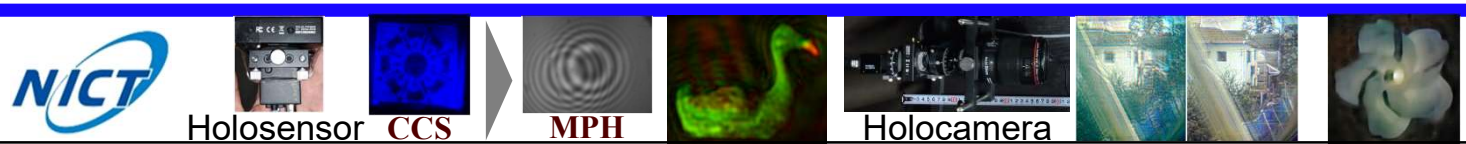
Summary

Incoherent digital holography for multidimensional motion-picture imaging was introduced.

Multidimensional information (3D, quantitative phase, wavelengths, polarization, and varieties of light) is obtained with IDH.

Improvement of specifications in IDH is achieved by
- introducing laser DH techniques,
- modifying optical designs,
- applying techniques of information science.

IDH has high potential for contributing to many research and application fields as advanced multidimensional sensor and imager.



tahara@nict.go.jp

Acknowledgements

Japan Science and Technology Agency (JST), PRESTO

The Mitsubishi Foundation

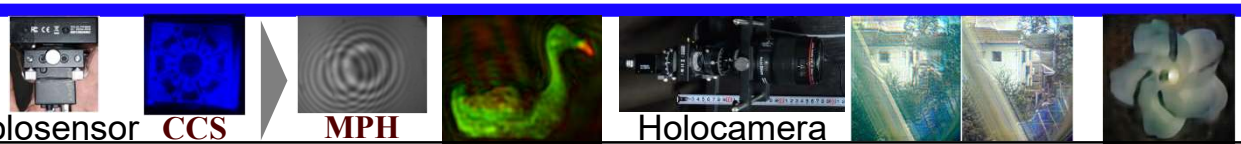
The Japan Society for the Promotion of Science (JSPS)

Cooperative Research Program of “Network Joint Research Center for Materials and Devices”.

Co-workers and co-authors related to IDH

Members of Applied Electromagnetic Research Center in NICT

Many journal staffs for supporting us



tahara@nict.go.jp

Advertisements

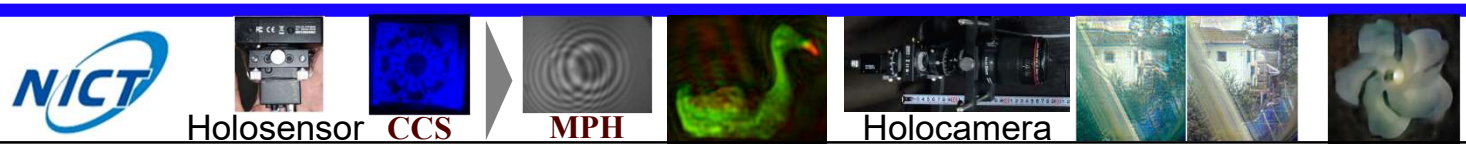
Roadmap and review articles have been published with researchers of IDH. Please use them for your IDH research.

Tatsuki Tahara, Yaping Zhang, Joseph Rosen, Vijayakumar Anand, Liangcai Cao, Jiachen Wu, Takako Koujin, Atsushi Matsuda, Ayumi Ishii, Yuichi Kozawa, Ryo Okamoto, Ryutaro Oi, Teruyoshi Nobukawa, Kihong Choi, Masatoshi Imbe, and Ting-Chung Poon, "Roadmap of incoherent digital holography," Applied Physics B **128** (2022) 193. https://doi.org/10.1007/s00340-022-07911-x

Joseph Rosen, Simon Alford, Vijayakumar Anand, Jonathan Art, Petr Bouchal, Zdeňek Bouchal, Munkh-Uchral Erdenebat, Lingling Huang, Ayumi Ishii, Saulius Juodkazis, Nam Kim, Peter Kner, Takako Koujin, Yuichi Kozawa, Dong Liang, Jun Liu, Christopher Mann, Abhijit Marar, Atsushi Matsuda, Teruyoshi Nobukawa, Takanori Nomura, Ryutaro Oi, Mariana Potcoava, Tatsuki Tahara, Bang Le Thanh, and Hongqiang Zhou, "Roadmap of recent progress in FINCH technology," Journal of Imaging **7** (2021) 197. https://doi.org/10.3390/jimaging7100197

Tatsuki Tahara, "Review of incoherent digital holography: applications to multidimensional incoherent digital holographic microscopy and palm-sized digital holographic recorder - holosensor," Frontiers in Photonics **2** (2022) 829139. https://doi.org/10.3389/fphot.2021.829139

Special thanks: Prof. Vijayakumar Anand for your kindness and great opportunities!

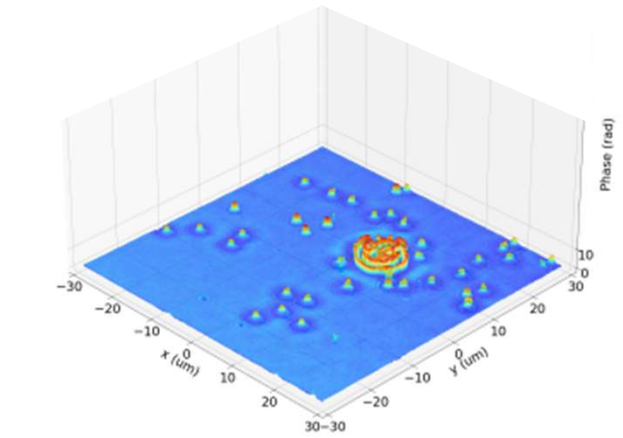


tahara@nict.go.jp

Thank you!

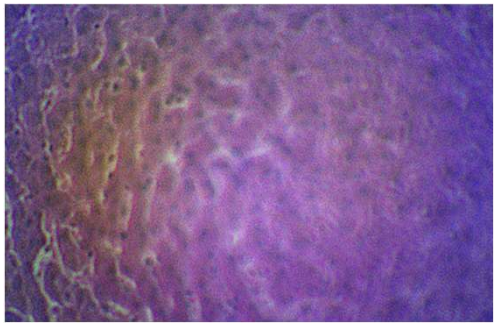
3D motion-picture imaging

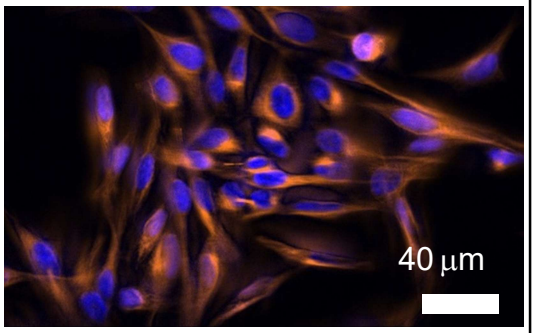
Opt. Express **30** (2022) 1182.
Applied Physics B **128** (2022) 193.
3DC2022, 2-1.



Multiple wavelengths

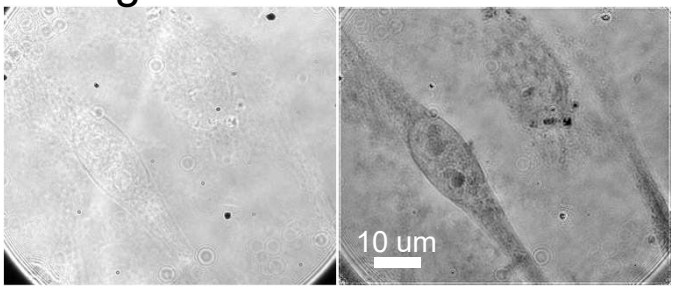
Appl. Phys. Lett. **117** (2020) 031102.
Opt. Lett. **45** (2020) 2482.
Appl. Opt. **60** (2021) A260.

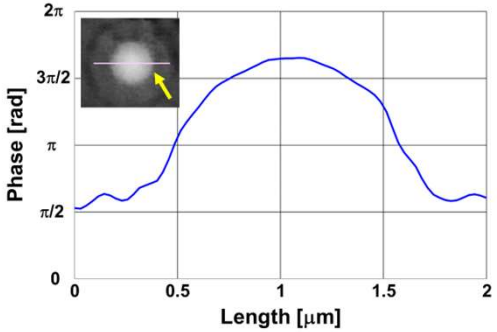




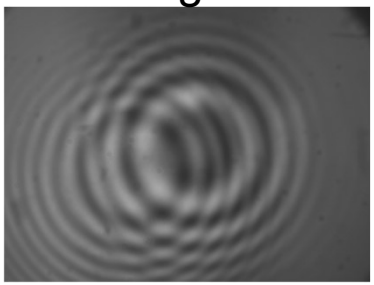
Bright field

Phase

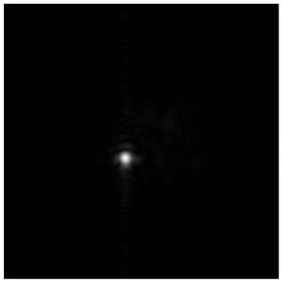




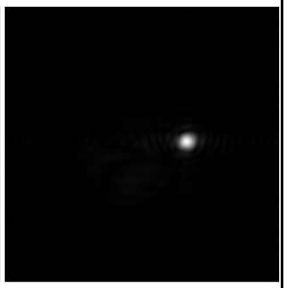
Multiplexed hologram



Transmission



Self-luminous



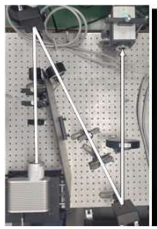
Quantitative phase

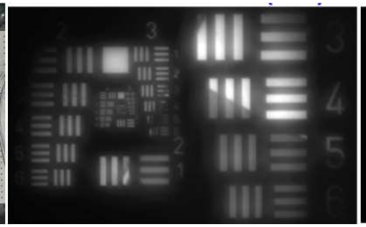
OSA Continuum **4** (2021) 2918.
Opt. Express **30** (2022) 1182.

Opt. Express **30** (2022) 21582.

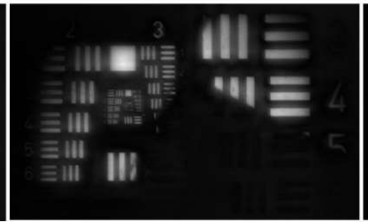
Identification of varieties of light

Recorded

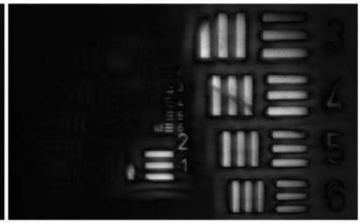




Horizontal



Vertical



Filterless polarization imaging