Relationship between the image quality and constant phase shifts in phase-shifting interferometry selectively extracting wavelength information

Tatsuki Tahara[1], Kaito Omae[1], Reo Otani[2], Yasuhiko Arai[1], and Yasuhiro Takaki[3]

[1]Kansai University, [2]SIGMAKOKI CO., LTD., [3]Tokyo University of Agriculture and Technology
E-mail: tahara@kansai-u.ac.jp

1. Introduction

Digital holography is a technique to record an object wave by utilizing interference of light and to reconstruct a 3D image using a computer. Color/multiwavelength digital holography is implemented by recording multiple wavelengths. A novel type of multiwavelength interferometry has been proposed, which is based on phase-division multiplexing of wavelengths [1-3]. Then, a restriction for phase shifts, which is required for firstly proposed scheme, is relaxed by the improved algorithm [4].

In this paper, a condition for properly utilizing the algorithm is numerically analyzed.

2. Phase-shifting interferometry selectively extracting wavelength information using arbitrary phase shifts

Figure 1 illustrates the schematic of the interferometry in the case where the number of wavelengths is two. Phase shifts for respective wavelengths α_1 and α_2 are introduced to obtain wavelength-multiplexed phase-shifted holograms $I(x,y{:}\alpha_1,\alpha_2)$ that are required for the technique. An object wave at an arbitrary wavelength is selectively extracted from the holograms recorded with arbitrary symmetric phase shifts. Only the complex amplitude distributions of object waves with different wavelengths $U_{\lambda1}(x,y)$ and $U_{\lambda2}(x,y)$ are separately derived from five wavelength-multiplexed phase-shifted holograms $I(0,0)$, $I(\alpha_1,\alpha_2)$, $I(-\alpha_1,-\alpha_2)$, $I(\alpha_3,\alpha_4)$, and $I(-\alpha_3,-\alpha_4)$, by the following expressions.

$$I(x,y{:}\alpha_1,\alpha_2) = 0th_{\lambda1}(x,y)+Ar_{\lambda1}(x,y)\{U_{\lambda1}(x,y)\exp(-j\alpha_1)+U_{\lambda1}^*(x,y)\exp(j\alpha_1)\} +0th_{\lambda2}(x,y)+Ar_{\lambda2}(x,y)\{U_{\lambda2}(x,y)\exp(-j\alpha_2)+U_{\lambda2}^*(x,y)\exp(j\alpha_2)\}, \quad (1)$$

$$U_{\lambda1}(x,y)=\{-I_1(1-\cos\alpha_4)+I_2(1-\cos\alpha_2)\} /2Ar_{\lambda1}(x,y)\{(1-\cos\alpha_2)(1-\cos\alpha_3)-(1-\cos\alpha_1)(1-\cos\alpha_4)\} + j(I_3\sin\alpha_4 - I_4\sin\alpha_2)/2Ar_{\lambda1}(x,y)(\sin\alpha_1\sin\alpha_4 - \sin\alpha_2\sin\alpha_3), \quad (2)$$

$$U_{\lambda2}(x,y)=\{I_1(1-\cos\alpha_3)-I_2(1-\cos\alpha_1)\} /2Ar_{\lambda2}(x,y)\{(1-\cos\alpha_2)(1-\cos\alpha_3)-(1-\cos\alpha_1)(1-\cos\alpha_4)\} +j(-I_3\sin\alpha_3+I_4\sin\alpha_1)/2Ar_{\lambda2}(x,y)(\sin\alpha_1\sin\alpha_4 - \sin\alpha_2\sin\alpha_3), \quad (3)$$

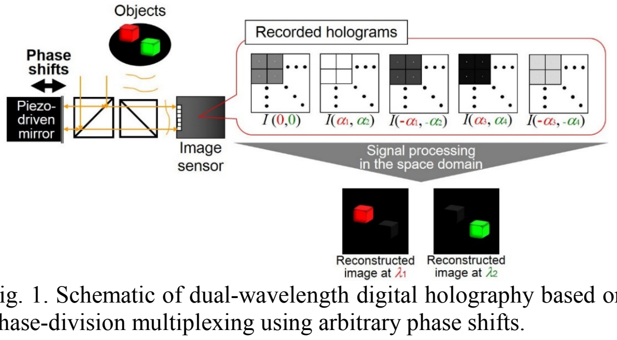

Fig. 1. Schematic of dual-wavelength digital holography based on phase-division multiplexing using arbitrary phase shifts.

where $0th(x,y)$ is the 0th-order diffraction wave, $Ar(x,y)$ is the amplitude distribution of the reference wave, j is imaginary unit, * means complex conjugate, $I_1 = I(x,y{:}0,0) - \{I(x,y{:}\alpha_1,\alpha_2) + I(x,y{:}-\alpha_1,-\alpha_2)\}/2$, $I_2 = I(x,y{:}0,0) - \{I(x,y{:}\alpha_3,\alpha_4) + I(x,y{:}-\alpha_3,-\alpha_4)\}/2$, $I_3 = \{I(x,y{:}\alpha_1,\alpha_2) - I(x,y{:}-\alpha_1,-\alpha_2)\}/2$, and $I_4 = \{I(x,y{:}\alpha_3,\alpha_4) - I(x,y{:}-\alpha_3,-\alpha_4)\}/2$, respectively. In the case where the number of wavelengths is N, multiwavelength information can be separately extracted from $2N+1$ holograms.

We conducted numerical simulations of the technique to investigate the relationship between the quality of the reconstructed image and the optical phase shift quantitatively. A standard image "Pepper" and smooth square pyramid were set as amplitude and phase images, respectively. Phase-shifted holograms at the wavelengths of $\lambda_1 = 632.8$ nm and $\lambda_2 = 532$ nm were spatially multiplexed. A monochromatic image sensor whose number of pixels was 2048 x 2048, pixel pitch 2.2 μm, and dynamic range 12 bits was assumed. Root-mean-square errors were calculated for the amplitude images reconstructed with constant phase shifts. Figure 2 shows the numerical results and indicates that a shift of the piezo-driven mirror should be without integral multiple of $\lambda/4$ to avoid π or 2π phase shift.

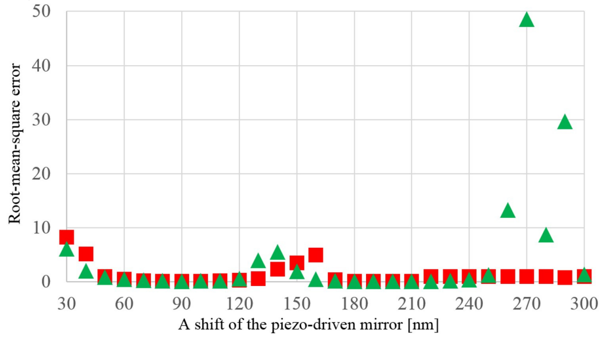

Fig. 2 Relationship between the quality of the reconstructed image and constant phase shifts.

3. Conclusion

We have clarified the relationship numerically. High-quality imaging can be done by adequate phase shifts.

This study was supported by Japan Society for the Promotion of Science (JSPS) (15K17474) and MEXT-Supported Program for the Strategic Research Foundation at Private Universities.

References

[1] T. Tahara, *et al.*, *DH2014*, DM3B.4 (3 pages), July 14, 2014.
[2] T. Tahara, *et al.*, *Opt. Lett.* **40** (2015) 2810.
[3] T. Tahara, *et al.*, *J. Opt. (IOP Publishing)* **17** (2015) 125707.
[4] T. Tahara, *et al.*, *DH2016*, DW5E.2 (3 pages), July, 2016.