Four-step in-line digital holography simultaneously sensing dual-wavelength information using wavelength-multiplexed holograms

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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. In the most recent report, a novel type of multiwavelength-imaging technique has been proposed, which is based on phase-division multiplexing of wavelengths [1,2].

In this paper, four-step dual-wavelength digital holography based on phase-division multiplexing is proposed.

2. Principle

Figure 1 shows the principle of the multiwavelength -imaging technique based on phase-division multiplexing of wavelengths [1,2]. Multiple-wavelength information is spatially multiplexed and separated in the polar coordinate plane. By applying the signal processing of phase-shifting interferometry, the desired wavelength information is extracted from wavelength-multiplexed images.

In the proposed technique, the number of the holograms required is decreased by utilizing two-step phase-shifting interferometry [3]. To implement phase-division multiplexing, wavelength-multiplexed phase-shifted holograms $I(0,0)$, $I(2\pi M,\alpha_2)$, $I(-2\pi M,-\alpha_2)$, and $I(\alpha_1,N)$ are recorded, where (α_1, α_2) are phase shifts at the wavelengths of (λ_1, λ_2), M is an integer, and N is an arbitrary known value. Also intensity images of the reference waves $A r_{\lambda 1}{}^2$, $A r_{\lambda 2}{}^2$ are recorded before/after measurement. From the holograms and reference intensity images, complex amplitude distributions of object waves $U_{\lambda 1}$, $U_{\lambda 2}$ are separately extracted. $U_{\lambda 2}$ is obtained as follows,

$$U_{\lambda 2} = [2I(0,0)-\{I(2\pi M,\alpha_2)+I(-2\pi M,-\alpha_2)\}]/\{4Ar_{\lambda 2}(1-\cos\alpha_2)\} + j\{I(2\pi M,\alpha_2) - I(-2\pi M,-\alpha_2)\}/(4Ar_{\lambda 2}\sin\alpha_2), \quad (1)$$

where, j is imaginary unit. From the extracted object wave $U_{\lambda 2}$ and $Ar_{\lambda 2}$, intensity distribution at only λ_2 component $I_{\lambda 2\mathrm{cal}}(\alpha_2)$ is numerically generated by a computer,

$$I_{\lambda 2\mathrm{cal}}(\alpha_2) = |U_{\lambda 2}|^2+Ar_{\lambda 2}{}^2 + Ar_{\lambda 2}\{U_{\lambda 2}\exp(-j\alpha_2) + U_{\lambda 2}{}^*\exp(j\alpha_2)\}. \quad (2)$$

After that, $I_{\lambda 1}(0) = I(0,0) - I_{\lambda 2\mathrm{cal}}(0)$ and $I_{\lambda 1}(\alpha_1) = I(\alpha_1,N) - I_{\lambda 2\mathrm{cal}}(N)$ are obtained to implement two-step phase-shifting interferometry. Finally, $U_{\lambda 1}$ is extracted by using two-step technique. When using Meng's technique [3], the expression is as follows,

$$U_{\lambda 1} = [\{I_{\lambda 1}(0)-a + j\{I_{\lambda 1}(\alpha_1)-I_{\lambda 1}(0)\cos\alpha_1-(1-\cos\alpha_1)a)\}]/2Ar_{\lambda 1}, \quad (3)$$

$$a = (v-\sqrt{v^2-4uw})/2u, \quad (4)$$

$$u = 2(1-\cos\alpha_1), \quad (5)$$

$$v = 2[(1-\cos\alpha_1)\{I_{\lambda 1}(0) + I_{\lambda 1}(\alpha_1)\} + 2\,Ar_{\lambda 1}{}^2\sin^2\alpha_1], \quad (6)$$

$$w = I_{\lambda 1}(0)^2 + I_{\lambda 1}(\alpha_1)^2 - 2I_{\lambda 1}(0)I_{\lambda 1}(\alpha_1)\cos\alpha_1 + 2Ar_{\lambda 1}{}^4\sin^2\alpha_1. \quad (7)$$

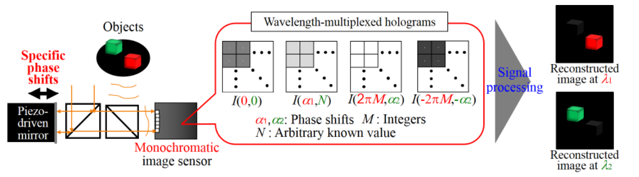

Fig. 1 Principle of multiwavelength-imaging technique based on phase-division multiplexing.

3. Numerical simulation

A numerical simulation was conducted to verify its effectiveness. A standard image "Pepper" was used as amplitude image. λ_1 = 640 nm and λ_2 = 532 nm were assumed as the wavelengths of the light sources. In these simulations, distance between the object and image sensor was assumed as 200 mm, pixel pitch as 5 μm, number of pixels as 512×512, and dynamic range as 8 bits. Phase shifts were set as (0,0), ($2\pi(\lambda_2/\lambda_1)$,0), (0, $2\pi(\lambda_1/\lambda_2)$), and (0,$-2\pi(\lambda_1/\lambda_2)$). Figure 2 shows the amplitude and phase distributions of the object wave at each wavelength and the images reconstructed by the proposed technique. Amplitude and phase images at each wavelength were clearly reconstructed. The results mean that a commercially available image sensor with 8-bit resolution is applicable to the proposed technique.

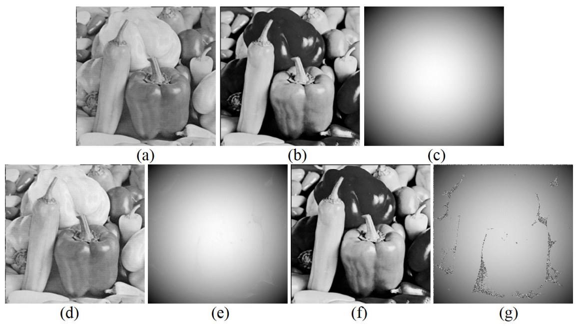

Fig. 2. Numerical results. Amplitude images at the wavelengths of (a) 640nm and (b) 532 nm and (c) phase image of the object. (d) Amplitude and (e) phase images at 640 nm and (f) amplitude and (g) phase images at 532 nm, which is reconstructed by the proposed technique.

4. Conclusion

Four-step dual-wavelength digital holography based on phase-division multiplexing is proposed. This will contribute to wide-area multiwavelength 3D imaging.

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References

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