Dual-wavelength digital holography using optical frequency synthesizer

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Digital holography (DH) [1] has become a topic of growing interest which finds its spot in the three dimensional imaging, as well as biomedical imaging and metrology. One practical limitation in DH with a single wavelength light is that it can only handle smooth profiles and step height less than half a wavelength ($\lambda/2$). To extend the dynamic range in depth over $\lambda/2$, dual-wavelength DH has been proposed [2]. In this method, DH is performed at two different wavelengths (λ_1, λ_2), and then the synthesized wavelength between them $\lambda_{1,2}$ $[= (\lambda_1\lambda_2)\ /|\ \lambda_1\text{-}\lambda_2|]$ is used to extend the dynamic range in depth up to $\lambda_{1,2}$. However, since stable CW laser oscillates at only a few discrete wavelengths, such as 532 nm, 633 nm, or 780 nm, it is difficult to obtain an arbitrary $\lambda_{1,2}$.

Recently, optical frequency comb (OFC) has emerged as a new technique for optical frequency metrology. OFC can be used as an optical frequency ruler by phase-locking a carrier-envelope-offset frequency f_{ceo} and a repetition frequency f_{rep} to a frequency standard. One interesting application of OFC is an optical frequency synthesizer (OFS), which is a single-mode CW laser phased locked to one optical frequency mode of OFC [3]. The absolute wavelength of OFS was secured by a frequency standard whereas the spectral linewidth was reduced to less than 0.01 pm. Furthermore, continuous tuning can be achieved by changing f_{rep} while keeping the phase-locking of CW laser to OFC. Such characteristics of OFS are attractive for dual-wavelength DH because $\lambda_{1,2}$ can be arbitrarily generated from μm order to mm order over m order depending on the sample. In this paper, we demonstrated dual-wavelength DH using OFS.

Figure 1 shows an experimental setup, which is composed of OFS and DH. In the OFS setup, after f_{ceo} and f_{rep} in OFC were respectively stabilized at 20 MHz and 250 MHz by referencing a rubidium frequency standard, an optical frequency of an extended cavity laser diode (ECLD, λ = 1500 ~ 1600 nm, mean power = 30 mW) was phase-locked to one mode of OFC. The linewidth of OFS was around 500 kHz whereas the stability and accuracy of its optical frequency were around 10^{-10} thanks to the frequency standard. In the DH setup, the output light from OFS was fed into a Mickelson interferometer after passing through a spatial filter. A test chart was placed as a sample in a object arm whereas a plane mirror was placed in a referenced arm. Two lights returning from the sample and the mirror were interfered in an off-axis configuration. The resulting hologram was acquired by an InGaAs camera (256 pixels by 320 pixels, pixel size = 25 μm). The phase image was calculated from the acquired hologram by using the Fourier deconvolution method [4].

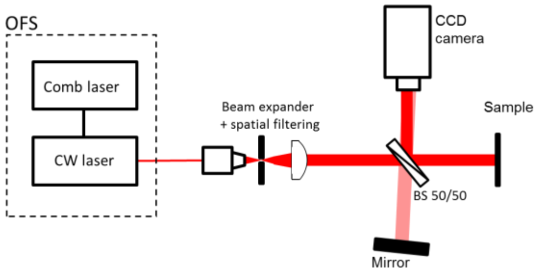

Figure 1 : Experimental setup

We first set the wavelength of OFS to 1560.0572 nm (λ_1) and acquired the corresponding hologram. Figure 2(a) shows the phase image of the test chart at λ_1. The phase wrapping was due to the tilt of the sample. Then, we tuned the wavelength of OFS to 1561.0097 nm (λ_2) and acquired the corresponding hologram. Figure 2(b) shows the phase image at λ_2, indicating the similar phase wrapping. Use of these two wavelength lights enables the $\lambda_{1,2}$ value of 2.556708 mm, which is three orders of magnitude longer than λ_1 or λ_2. Finally, we obtained the phase image at $\lambda_{1,2}$ after dual-wavelength unwrapping process [5] as shown in Fig. 2(c). The phase image did not indicate the phase wrapping due to the extended dynamic range of depth. These results indicate a potential of DH for 3D imaging of an object with large step.

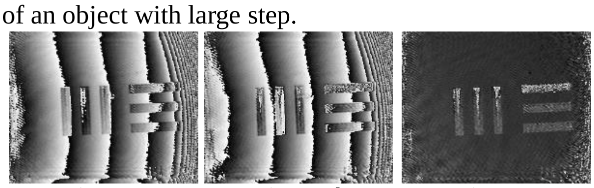

Figure 2a *Figure 2b* *Figure 2c*

Figure 2: Reconstructed phase images for λ_1 (Fig. 2a), λ_2 (Fig. 2b), and after unwrapping (Fig. 2c).

In summary, we combined dual-wavelength DH with OFS and demonstrated its potential for 3D imaging with wide dynamic range of depth.

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