Numerical multiplexing and de-multiplexing techniques for efficient storage and transmission of digital holographic information

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1 Introduction

Digital Holograms can be multiplexed by encoding the information of two or more holograms in a single one. Multiplexing of digital holograms has been used to measure some object properties, as the state of polarization, by a single image acquisition [1]. Other applications of multiplexing techniques in holography regard the investigation of ultra-fast events [2], or experiments in which a diffraction grating is used to get super-resolved images increasing synthetically the numerical aperture of the image sensor [3].

Actually, in the most of the above mentioned approaches, spatial multiplexing of digital holograms is obtained optically, that means recording simultaneously more then one fringe pattern on the same sensor array. All the holograms are superimposed in one composite CCD frame, and each of them can be independently reconstructed after the digital spatial filtering in the Fourier spectral domain of the multiplexed hologram.

However, the multiplexing operation can be carried out also by numerical techniques by combining numerically digital holograms to obtain a single synthetic hologram. Recently, we demonstrated that an efficient storage and/or transmission of a large number of digital holograms can be attained by numerical multiplexing (NM) method [4]. The results obtained are reported in the section 3.

2 Experimental set-up

The multiplexed holograms are acquired by means of a Mach-Zehnder interferometric microscope, shown in Fig.1. The laser wavelength is 532 nm and the microscope objective is a 20 X objective with a focal length *f* =9.0 mm and a NA=0.40. The CCD detector has 1280 X 1024 square pixel which size P_{CCD} = 6.7 µm. To obtain the multiplexed hologram, we exploit the single capability of DH to manage numerically the complex wavefronts, to reconstruct the object wave field at an intermediate plane, that is, essentially, the back focal plane (BFP) of the imaging lens

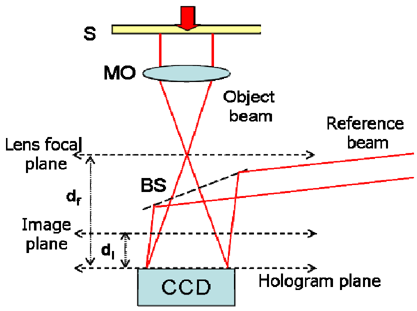


Fig. 1. Sketch of the DH setup; S: sample; BS: beam splitter; MO: microscope objectives.

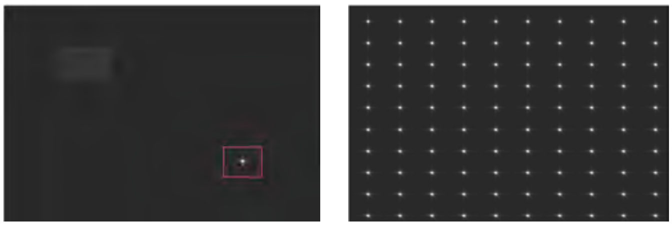
In the BFP of the imaging lens, the complex-value array, corresponding to the object wavefield, is proportional to the Fourier transform of the complex amplitude of the wave at an input plane. Therefore, we obtain only the spectrum of the object wave field, removing the contribution of the carrier frequencies.

3 Numerical multiplexing and de-multiplexing

Here we described the method we use for the numerical multiplexing and de-multiplexing of up to 100 digital holograms. Firstly, we will show how the holograms are multiplexed and, then, how the multiplexed hologram is processed in order to reconstruct all one hundred amplitude and phase maps. Finally, these reconstructed images are compared with those one obtained by the original holograms and the distortions caused by the multiplexing are evaluated.

The specimen is an in vitro mouse preadipocyte 3T3-F442A cell. It has been monitored for 25 hours to investigate its activities and one hundred holograms have been recorded with an acquisition rate of 4frame/ hour.

Moreover, a reference hologram is acquired in a area of the sample far from the cell in order to calculate the phase retardation caused only by the cell subtracting the phase shift due to the interferometer and the culture medium. Each of the hologram is reconstructed in the BFP of the MO. The amplitude reconstruction of one hologram in the BFP is shown in Fig.2(a).



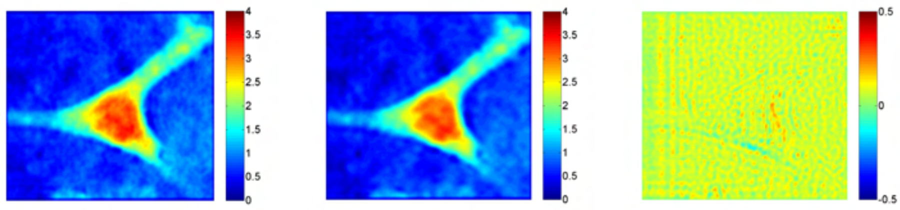
(a) (b)

Fig. 2. (a) Amplitude reconstruction of one hologram in BFP. The red frame indicates the used filtering window around the carrier frequency of the object spectrum. (b) Amplitude of the synthetic spectrum obtained by the numerical multiplexing in the BFP of 100 digital holograms.

Then, we choose a mask to filter each hologram in the BFP. The red frame in Fig.2(a) indicates the shape and the dimension of the used filtering window, that is 50 X 50 pixels around the carrier frequency of the object spectrum, whose position depends on some geometrical parameters of the experimental setup. The transmittance of the mask is 1 within the frame and 0 outside. Obviously, reducing the dimension of the filtering window will increase the number of holograms we can encode in one single hologram. On the other hand, the size of the filtering window should be larger than the object bandwidth in order to retain the spectral information. To properly multiplex the holograms in the BFP, we join together the 100 filtered spectra. The amplitude of the synthetic spectrum obtained in this way is shown in Fig.2(b). This complex-value array contains the information about the phase and amplitude of all one hundred holograms.

In the de-multiplexing process, the hologram composed in the BFP is filtered selecting one by one the single holograms that, then, are numerically reconstructed in the image plane.

In Fig. 3 are shown the phase reconstructions of one hologram as acquired by the CCD (a) and after the multiplexing/de-multiplexing process (b). Comparing the two reconstructions, the distortion caused by the filtering process is not evident. In Fig.3 (c) we have plotted the difference between the two phase reconstructions in order to evaluate the distortion.



(a) (b) (c)

Fig. 3. Phase reconstructions of one hologram as acquired by the CCD (a) and after the multiplexing/de-multiplexing process (b). Difference between the two phase reconstructions in Fig. 3(a) and 3(b).

Then, we calculated the mean value of the 2D distribution of this phase difference that results 0.068 rad with a variance of 1 * 10-3 rad, while the maximum value is 0.23 rad. The maximum phase difference is situated on the cell border. This result is caused by the use of the filtering window that acts as a band-pass filter with limited bandwidth, cutting the high frequencies due to the edges.

In conclusion, we proposed an all numerical technique to multiplexed and de-multiplexed correctly up to 100 DHs. This technique could be useful to perform an efficient storage and/or a fast transmission of DHs from the recording head to the display unit.

4 References

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