Adaptive deformation of digital holograms for full control of depth-of-focus in 3D imaging

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Summary

We show that through an adaptive deformation of digital holograms it is possible to manage the depth of focus in the numerical reconstruction. Deformation is applied to the original hologram with the aim to put simultaneously in-focus, and in one reconstructed image plane, different objects lying at different distance from the hologram plane (i.e. CCD sensor), but in the same field of view. In the same way it is possible to extend the depth of field for 3D object having a tilted object whole in-focus.

Introduction

In respect to other interference microscopy techniques, digital holography has the unique feature to let to explore, by means of numerical diffraction propagation, the volume in front the hologram plane (i.e. the detector plane). In fact, it is possible to image objects at different distance from the CCD plane, by the numerical reconstruction of the holograms in planes that are parallel to the hologram but at different distances [1]. However, for objects having 3D extension or 3D shape, only some portions of the object can be in good focus in each of those planes [2]. In classical optical microscopy the problem is solved by scanning mechanically the 3D volume with the aim to extract “in-focus” information. By such a procedure it is possible to build-up a single image, named Extended Focus Image (EFI), in which all points of the object are in-focus. Here we propose a new Digital Holography method to solve this problem by an adaptive deformation of digital holograms that allow to manage and control the depth of focus in numerical reconstructions.

Experimental Methods

Considering a digital hologram of an object at distance d from the CCD, the numerical reconstruction of the object in focus is obtained adopting the numerical modelling of the diffraction Fresnel propagation integral.

If an affine geometric transformation, a deformation, is applied to the original recorded hologram h, consisting in a simple stretching described by $[\xi' \eta'] = [\xi \quad \eta \quad 1] T$ through the operator

$$T = \begin{bmatrix} \alpha & 0 \\ 0 & \alpha \\ 0 & 0 \end{bmatrix} \tag{1}$$

given by $h(\xi', \eta') = h(\alpha\xi, \alpha\eta)$ we obtain that the propagation integral changes as follows,

ISBN 978-3-00-024191-8

$$B(x,y,d)=\frac{1}{i\lambda d}e^{ikd}\iint h(\alpha\xi,\alpha\eta)e^{\frac{ik\alpha^2(x-\xi)^2}{2d\alpha^2}}e^{\frac{ik\alpha^2(y-\eta)^2}{2d\alpha^2}}d\xi d\eta=$$

$$=\frac{1}{i\alpha^2\lambda d}e^{ikd}\iint h(\xi',\eta')e^{\frac{ik(x'-\xi')^2}{2D}}e^{\frac{ik(y'-\eta')^2}{2D}}d\xi' d\eta'=\frac{1}{\alpha^2}b(x',y',D) \qquad (2)$$

From Eq.(2) it is clear that the new hologram reconstructs the object in focus at a different distance D $=\alpha^2$ d. The hologram has been simply stretched and we name α the elongation factor. The impact that the stretching has on numerical reconstructions, is shown in Fig.1. The object was made of three different wires positioned at different distances from the CCD array. The horizontal wire, the twisted wire with the eyelet and the vertical wire were set at distances of 100mm, 125mm and 150mm, respectively. The numerical reconstructions at the above distances give an image in which each wire at a time is in good focus, as shown in Fig. 1a, 1b and 1c, at the corresponding recording distances. When the hologram h(x,y) is uniformly stretched with an elongation factor along both dimensions (x,y) of α=1.1, the horizontal wire results to be in focus at a distance d=150 mm (Fig. 1d) instead of 100mm. If α=1.22, the twisted wire with the eyelet is in focus at d= 150 mm (Fig. 1e)

instead that at d=125mm. Anyway, the results shown in Fig.1 demonstrates that the depth of focus can be controlled by means of the uniform stretching of the holograms according to Eq.(2).

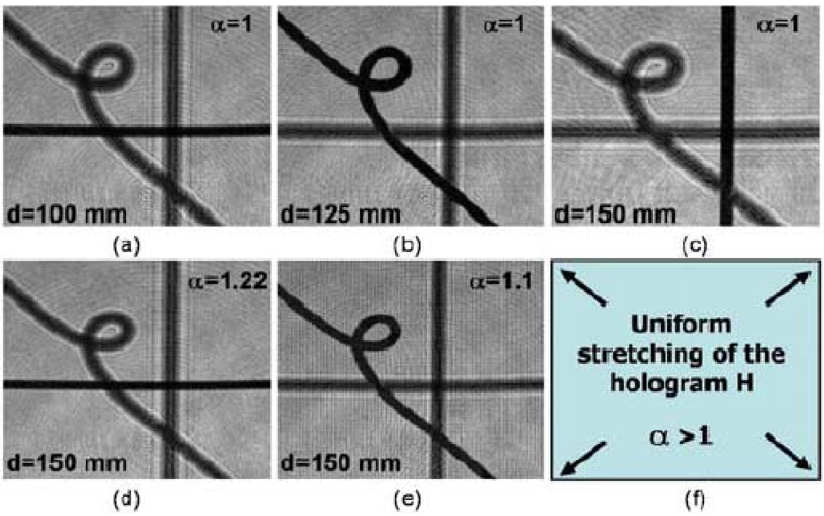

Fig. 1: The Reconstruction of a digital hologram as recorded (no-stretching) at three different distances with each wire in focus at distance of (a) 100mm, (b) 125mm and (c) 150 mm, respectively. When the holograms is stretched with α=1.1 the horizontal wire is in focus at distance of d=150 mm (d) while for α=1.22 the curved wire is in focus even at d=150 mm (e). Conceptual draw of the stretching of H (f).

This interesting results implies that by opportune and adaptive deformation of digital holograms, different parts of the 3D scene that are a different depths can be obtained in good focus in a single reconstructions.

References

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