

Fresnel Incoherent Correlation Holography using Lucy-Richardson-Rosen Algorithm

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Abstract: Fresnel incoherent correlation holography (FINCH) is a super-resolution imaging method which requires at least three camera shots to image an object. In this study, we have demonstrated single-shot FINCH using a recently developed Lucy-Richardson-Rosen algorithm. © 2022 The Author(s)

1. Introduction

Fresnel incoherent correlation holography (FINCH) was developed in 2007 by Rosen and Brooker [1]. In FINCH, the light from an object is split into two, modulated using two different quadratic phase masks and interfered to form the self-interference hologram. At least three such self-interference holograms are recorded with different phase shifts between the interfering beams and combined to remove the twin image and bias terms that are usually present in an inline hologram. The first version of FINCH used spatial random multiplexing of two quadratic phase masks to generate the self-interference holograms. However, the signal to noise ratio (SNR) in the above scheme was low which lead to the development of polarization multiplexing method [2,3]. While the above method improved the SNR, the need for three camera shots, significantly affected the performance of FINCH. Alternative methods using polarization multiplexing with 4-pol camera [4], spatial multiplexing to fit four camera shots within the sensor area [5,6] were developed. Even though the above methods were successful in converting four camera shots into one by some multiplexing approach, the original problem of requirement of multiple camera shots of FINCH was not addressed. Most recently, a two-step phase-shift FINCH was developed utilizing the mathematical model of self-interference holography and implemented FINCH with two camera shots [7]. A radically different approach of single shot FINCH was demonstrated by prerecording the point spread hologram (PSH) and correlating it with the FINCH hologram of an object using non-linear reconstruction [8-10]. In that approach, the optical modulator of FINCH was designed based on the configuration of the first version of FINCH by randomly multiplexing two quadratic phase functions and manufactured as a passive optical element using electron beam lithography. The results were remarkable but the SNR was low. Recently, a new computational reconstruction method called Lucy-Richardson-Rosen algorithm (LRR) was developed by integrating the well-known deconvolution method Lucy-Richardson algorithm (LRA) and non-linear reconstruction (NLR) [11-13] method developed by Rosen. For deterministic optical fields, the performance of LRR was better than LRA and NLR. In a study involving rotating point spread functions, the experimental results of NLR was better than LRR and LRA [14]. In this study, we have applied LRR to FINCH for the first time.

2. Methods

The optical configuration of FINCH with polarization multiplexing scheme is shown in Figure 1(a). Light from an object located at a distance of z_s from the lens L is collimated and polarized at 45° with respect to the active axis of a spatial light modulator (SLM). In the SLM, the phase of a quadratic phase mask $Q(-2/z_h)$ is displayed, where $Q(1/z) = \exp(j\pi R^2/\lambda z)$, where R is the radial coordinate. At the SLM, only part of the light is modulated and so two beams are generated. These two beams propagate without any interaction as their polarization states are orthogonal to one another. After the second polarizer oriented at 45° with respect to the active axis of SLM, the resulting two beams have the same polarization and coherently interfere generating the self-interference hologram. For a single point in the object plane, the resulting intensity distribution can be expressed as $I_{PSH} \approx [\exp(j2\pi R^2/\lambda z_h) + 1]^2$, where I_{PSH} is the

point spread hologram. The object intensity pattern I_O obtained for an object O is given as $I_O = O \otimes I_{PSH}$, where \otimes indicates convolution. In FINCH, it is possible to reconstruct the object information as $I_R = I_O * I_{PSH}$, which can be rewritten as $I_R = O \otimes (I_{PSH} * I_{PSH})$, where $*$ indicates correlation. The NLR approach of the cross-correlation in FINCH reconstructed the object information but with a low SNR. The LRRA shown in Fig. 1(b) utilizes non-linear correlation to improve the maximum likelihood estimation in fewer iterations unlike LRA and reconstructs object information with a relatively higher SNR.

The experimental setup used a collimated LED emitting at 532 nm (FWHM = 35 nm). A lens ($f=100$ mm) was placed to critically illuminate the pinhole, located in the object plane. The light from the pinhole is polarized to 45° orientation by a polarizer, collimated and the beam is reflected by a phase-only SLM (1920×1080, Pixel pitch: 8 μm) which displayed a Fresnel zone plate with a focal length of 200 mm. Two beams: one modulated by SLM and the other unmodulated are created at the SLM. A second polarizer with an orientation of 45° perpendicular to the first polarizer was introduced so that the two beams can interfere with one another. An image sensor (1392×1040 pixels with 6.45 μm square pixels) recorded the FINCH holograms. The image of the recorded PSH is shown in Fig. 1(c). A test object “DH & 3D Imaging” (Fig. 1(d)) was used and the corresponding FINCH hologram was estimated from the experimentally recorded PSH as shown in Fig. 1(e). The optimal reconstruction result using LRRA for $\alpha = 0$, $\beta = 0.5$, and number of iterations 3 is shown in Fig. 1(f).

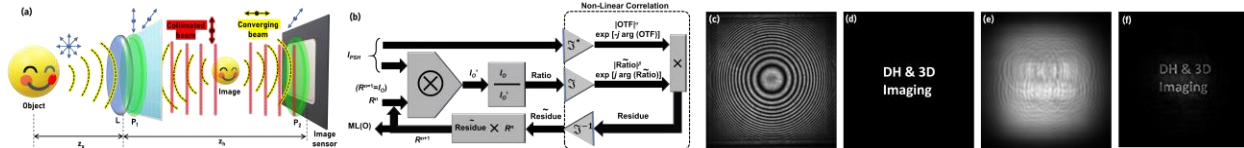


Figure 1. (a) Optical configuration of the FINCH in polarization multiplexing scheme. (b) Schematic of LRRA. (c) Experimentally recorded PSH. (d) Test object. (e) Synthetic object hologram and (f) reconstructed image using LRRA.

3. Discussion and Conclusion

In this study, the newly developed LRRA has been applied for reconstructing FINCH hologram for the first time. The PSH was experimentally recorded in the experimental set up of FINCH in polarization multiplexing scheme and the object hologram for a test object was synthesized. The object hologram was reconstructed using LRRA. The preliminary results are promising. We believe that this study will lead to the development of compact and light-weight, super resolution single-shot FINCH microscopes.

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