Digital Holography of Natural Scenes

Myung K. Kim
Department of Physics, University of South Florida, Tampa, Florida 33620 , USA
Tel: +1-813-974-5223, Fax: +1-813-974-5813, E-mail: mkkim@usf.edu

Abstract: A novel technique dubbed self-interference incoherent digital holography (SIDH) is being developed for imaging of natural scenes such as astronomical objects or daylight-illuminated outdoor scenes.

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The basic principle of the holographic imaging, which requires the coherent light source, prevents its widespread use in practical applications. Hence there have been many efforts to record the hologram under the condition of the incoherent illumination since the early years of the history of the holographic imaging [1]. In recent years, there have been several successful reports about this issue with various different approaches [2-4]. One of the most attractive approaches is the Fresnel incoherent correlation holography (FINCH) which uses the self-coherence of point sources by using the spatial light modulator (SLM) which can operate as the combination of a concave mirror and a simple flat mirror [4]. Though the spatial incoherence between the point sources washes out the interference pattern as the number of the point source increases, the adoption of the digital imaging devices such as the charge coupled device (CCD) makes it possible to obtain the complex hologram by the phase shifting method. Recently, we have presented the self-interference incoherent digital holography (SIDH) scheme that can be applied to the astronomical telescopic imaging with capabilities to compensate for atmospheric aberration [5, 6]. The SIDH is also used in generating full color three-dimensional imaging of outdoor scenes under natural daylight illumination. This paper presents recent progress in SIDH development [7].

The essential configuration of SIDH is based on a modified Michelson interferometer. A beam splitter produces two copies of a spherical wave from each object point, which are reflected by two mirrors of different curvatures. The two resultant spherical waves are superposed at the CCD plane creating the Fresnel-zone-like interference pattern. Thus the SIDH interferometer has resultant optical effect similar to FINCH, in that it produces from each source point two copies of spherical wave with different curvatures. This is achieved without use of phase-only spatial light modulator. In both FINCH and SIDH, the three-dimensional location of each source point is encoded by the frequency and center location of the Fresnel zone pattern produced by the interference of two spherical waves. The ambiguity of the twin diffraction terms as well as the zero-order term can be removed by phase-shifting with a piezo-mounted mirror, just as in ordinary phase shifting digital holography. Because of the spatial incoherence of naturally illuminated objects, the Fresnel zone-like fringes from source points quickly accumulate incoherently for any continuous or extended objects, obliterating any such interference patterns. But the phase-shifting process yields complex spherical phase fronts from individual point sources that add coherently, which is the key principle of FINCH or SIDH.

The complex hologram from SIDH therefore contains both amplitude and phase profiles. The phase profile of SIDH does not represent the phase of the object's optical field – the object is spatially incoherent, after all – but it does contain information on the optical path, including any aberrations of the optical path. It turns out that, under certain conditions analogous to conventional adaptive optics, the complex hologram is affected by aberrations in a deterministic way that can be compensated for if the hologram of a point source – a guide star – is available. A set of three LEDs are used as the object for SIDH imaging in Fig. 1a), obtained by numerical focusing of the complex hologram. Such hologram has three-dimensional imaging characteristics, in that object points at different distances numerically focus at different distances – though not illustrated in this example. When a phase aberrator, in the form of irregular shaped piece of clear plastic, is placed in front of the interferometer, Fig. 1b) is the best-focus image, with obvious degradation. Another complex hologram of a single point source can be used for correlation with the aberrated full-field hologram to compensate for the aberration. Numerical propagation from such compensated hologram shows much improved holographic image in Fig. 1c). Thus SIDH provides a new approach to adaptive optics and aberration compensation, without the optomechanically cumbersome and expensive wavefront sensors or deformable mirrors. SIDH has potential to make adaptive optics accessible and affordable to a wide range of applications.

The SIDH can be used to acquire 3D holographic images of common outdoor scenes, illustrated in Fig. 2. A color ccd camera is used on the same interferometer as above. The three color channels of the ccd output are separated and analyzed individually to obtain the red, green, and blue component holograms. The resultant amplitude images are then combined to produce three-dimensional full-color holographic images of daylight-illuminated outdoor scenes. The three-dimensional content of the holographic image is demonstrated by numerically focusing to different distances in Fig. 2a) and b). To my knowledge, this is the first ever holographic image of outdoor scenes under daylight illumination.

The incoherent digital holography techniques, including SIDH, opens up a large range of new applications and capabilities of holographic imaging, by removing the seriously constraining requirement of coherent lasers as illumination sources. One can expect applications in all areas of imaging such as astronomy, remote sensing, and fluorescence imaging, as well as in non-optical wavelengths such as in x-ray and THz imaging.

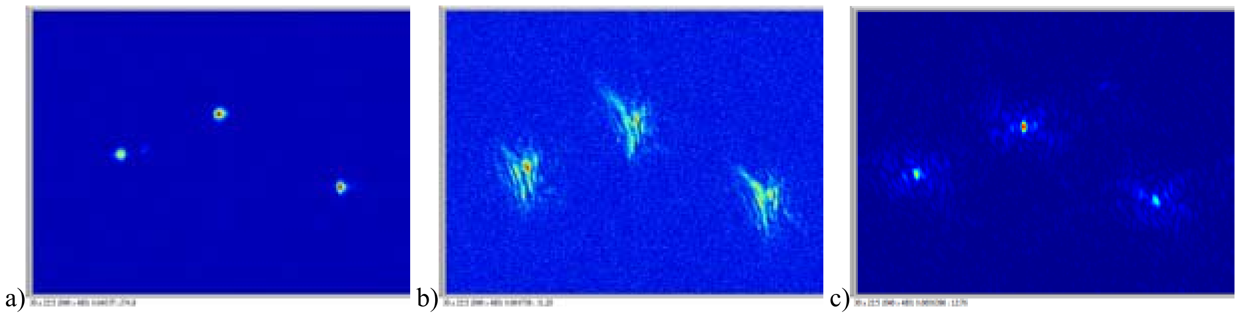

Fig. 1. Aberration compensation and adaptive optics by SIDH, demonstrated using LEDs: a) SIDH holographic image without phase aberrator; b) image with an aberrator in place; c) aberration-compensated by correlation with SIDH hologram of a guide star.

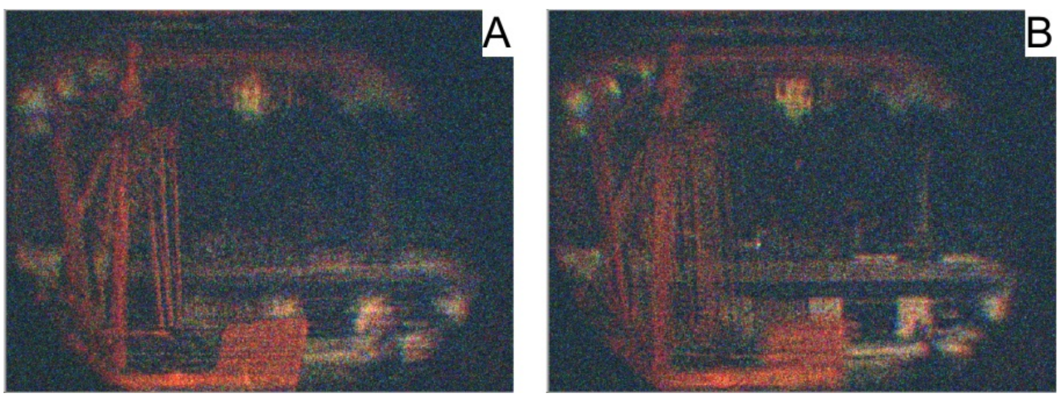

Fig. 2. Two images calculated from a hologram, showing the image focused (A) on the close toy boat, and (B) on the distant buildings.

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