SPIE Newsroom

10.1117/2.1201304.004842

New method for recording digital holograms

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Fourier incoherent single-channel holography can record spatially incoherent digital holograms, avoiding the twin-image problem. This could enable the development of instruments such as holographic telescopes and video cameras.

Recent noteworthy advancements in the field of incoherent digital holography (the production of 3D images) include optical scanning holography and Fresnel incoherent correlation holography (FINCH) techniques.[1,2] The latter acts as a single channel incoherent interferometer (a device that splits light into two beams and recombines them to produce an interference pattern) and does not require any scanning or mechanical movement, therefore making FINCH fundamentally robust.

There is a well-known issue in holography known as the twin image problem. It commonly arises in holograms that are recorded by a single exposure, and where the reference and signal beams hit the camera with the same, or similar, angle. When such holograms are reconstructed, the virtual and real images emitted from the hologram in the same direction cannot be separated. This results in an obtained image that appears as a blurred noisy pattern. With Finch, although a single image contains the complete 3D information of an object, at least three images are required to solve the twin image problem.[2]

Our new holographic method overcomes the twin image problem through the recording of a Fourier hologram.[3] This method, Fourier incoherent single channel holography (FISCH), exploits the beneficial qualities of Fourier holograms over those of Fresnel holograms. These include: increased space-bandwidth performance; enhanced robustness to information loss, as each object point is distributed over the entire hologram plane; and easier filtering ability, since the hologram is captured in the spatial frequency domain.[4] By recording a Fourier hologram of a half plane (or space), the twin image problem is avoided and the object can be reconstructed from a single exposure. In addition, our method maintains many of the other advantageous characteristics of FINCH, including its inherent super-resolution property.[5]

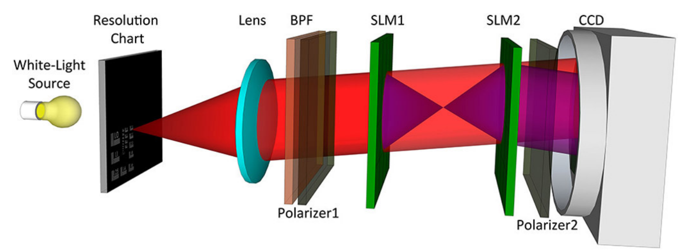

Figure 1. *Schematic of a Fourier incoherent single channel holography (FISCH) recorder. BPF: bandpass filter; SLM: spatial light modulator.*

In the FISCH system (see Figure 1), a 3D object is illuminated by a white-light source. Light scattered from the object is gathered by a lens and becomes partly temporally coherent once it has passed through a band pass filter. The light continues to propagate through a single channel incoherent interferometer that utilizes polarization-sensitive phase-only spatial light modulators (SLMs). A diffractive optical element of the same converging lens is displayed on each of the two SLMs. Together, they form an afocal optical system with a magnification of minus one. We introduce a polarizer before the polarization-sensitive SLMs, and align it at a 45° angle to the polarization sensitive axis of the SLMs. This causes the light-beam within the single channel interferometer to be effectively split into two beams, only one of which is affected by the two diffractive lenses of the afocal system.[6] The second polarizer in our system is also rotated 45° to the active axis of the SLMs and enables the interference of the two beams, which is recorded by the CCD. Since each point source is only spatially coherent to itself, the recorded hologram is simply a summation over all the point source contributions. For a point located at the front focal plane of the input lens in Figure 1, the interference pattern is due to two plane waves of opposite inclinations, which indicates the formation of a Fourier hologram.

We have analytically shown that the recorded holograms are Fourier in nature.[3] The interference pattern of each point

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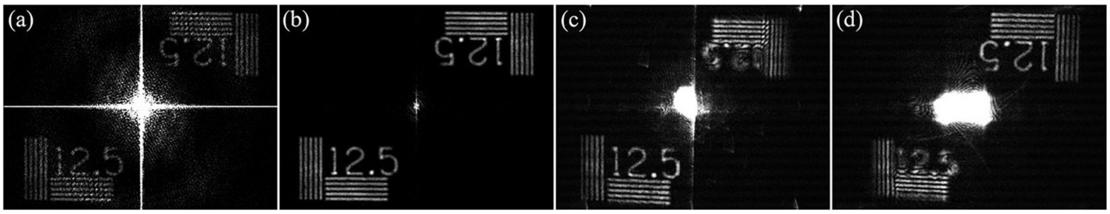

Figure 2. *Digitally reconstructed images of (a) a single exposure and (b) two-exposure holograms, recorded with the target at the front focal plane of the input lens. Optically reconstructed images of a two-exposure hologram recorded with the target outside the front focal plane of the input lens, where (c) the image and its twin are in, and out of focus, respectively; and (d) where the image and its twin are out of, and in focus, respectively.*[3]

source encodes the 3D position of the source and its intensity. In addition, we have demonstrated that the complete 3D information of an object can be digitally reconstructed from a single exposure real-valued hologram. Both FISCH and FINCH have the same point spread function, therefore FISCH has an improved resolution compared to conventional imaging as it exceeds the limit dictated by the Rayleigh criterion (the common criterion for the minimum resolvable detail).[5]

Our experimental results are shown in Figure 2. The first hologram was recorded with the resolution test chart positioned at the front focal plane of the input collimating lens. The reconstruction results, shown in Figure 2(a) and (b), are simply the inverse Fourier transform of the various holograms. Figure 2(a) demonstrates that a single exposure is sufficient for retaining most of the target information. However, the 0^{th} order is clearly visible in the center of the image, where it dominates the hologram and reduces the quality of the image. Using two exposures, as in Figure 2(b), greatly reduces the bias term, increases the dynamic range of the hologram, and thereby enhances the quality of the image. To demonstrate the system's capability of maintaining 3D information, another hologram was recorded with the resolution test chart positioned at a shorter distance from the lens. Since the holograms of the two exposures have purely real values, they can also be easily reconstructed optically using commercially available amplitude SLMs. The optical reconstructions in Figure 2(c) and (d) clearly demonstrate the refocusing capability of the system, where the image and its twin are in and out of focus, respectively. This was achieved through a back and forth movement of the CCD along the z-axis.

Our next design of FISCH will be based on a more general configuration in which the maximum optical path difference will be substantially reduced. This will offer higher signal to noise ratios and the possibility to use light sources with wider bandwidths. We believe that combining the capability of recording single exposure holograms under incoherent illumination, together with its inherent robustness, will make possible several possible applications for FISCH that may include holographic video cameras, fluorescence microscopes, and telescopes.

This work was supported by the Israeli Ministry of Science and Technology (MOST) and by the Israel Science Foundation (ISF).

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