IMAGING THROUGH TURBID MEDIA

Imaging through Partially Occluding Media Using Compressive Sensing

The imaging of a partially occluded target object is an active area of research.[1,2] It is usually addressed using multi-aperture systems in which different views of the object can be revealed by applying synthesis algorithms. These techniques often require substantial scanning and are limited by the numerical aperture of a single perspective, which may yield low-resolved object details.

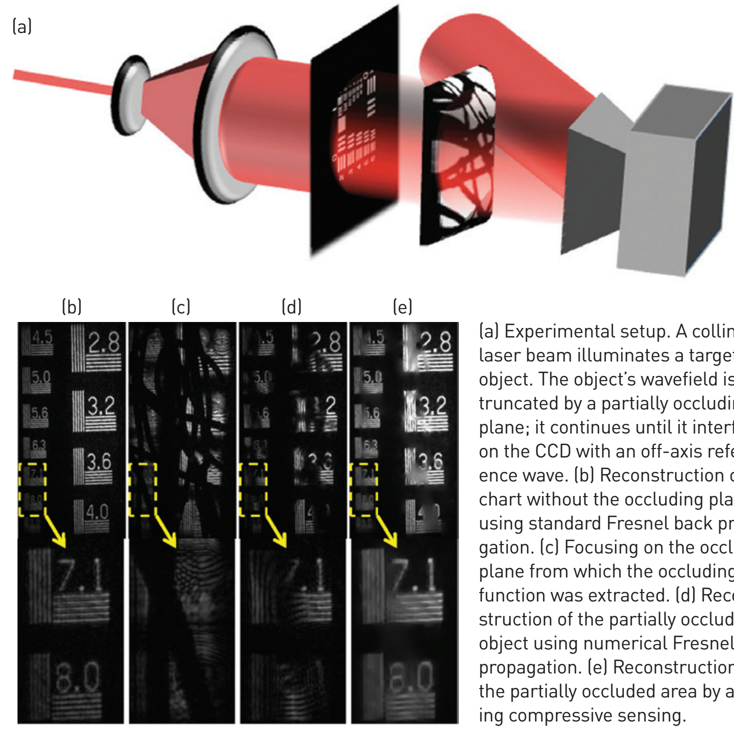
We present a method that can be implemented with a single shot and single aperture holographic and computational reconstruction.[3] Object recovery was recast as a compressive sensing (CS) problem, where the sensing mechanism is based on the free space propagation of the object's wavefield. CS is a joint signal acquisition-reconstruction paradigm that has gained much attention because it provides a framework for reconstructing highly subsampled signals.

Digital holography is an efficient object sensing scheme when combined with CS; a signal can be reconstructed from a subsampled Fresnel/Fourier hologram.[4] This motivated us to try recovering an object whose wavefield was partially blocked by the occluding environment.

For the experiment, we recovered an Edmund Optics 1951 USAF transmission resolution chart, which was illuminated by a HeNe laser beam at 632 nm. We used a twisted, blackened barb wire as partially opaque media and an off-axis setup to record the hologram. By numerically refocusing the wire plane, we evaluated its structure and found that approximately 59 percent of the resolution chart's field was obscured.

The figure shows reconstruction results for a non-occluded object (as a reference), numerical focusing on the occluding plane, and the occluded object reconstructed via standard numerical back propagation and CS. The reconstruction with the CS approach reveals details that are lost in the reconstruction with numerical back propagation.

We treated the occluding object as planar and binary. Given the physical properties of the media (e.g., opacity percentage and physical structure), one can theoretically determine the minimal number of objects that can be reconstructed.[3] That is demonstrated in our online video. Since the analytical results also apply to complex media, the method can be used to recover objects behind turbid media.[5] OPN



(a) Experimental setup. A collimated laser beam illuminates a target object. The object's wavefield is then truncated by a partially occluding plane; it continues until it interferes on the CCD with an off-axis reference wave. (b) Reconstruction of chart without the occluding plane using standard Fresnel back propagation. (c) Focusing on the occluding plane from which the occluding function was extracted. (d) Reconstruction of the partially occluded object using numerical Fresnel back propagation. (e) Reconstruction of the partially occluded area by applying compressive sensing.

Visit **www.opnmagazine-digital.com** to view the video that accompanies this article.

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References

1. B. Javidi et al. Opt. Lett. **31**, 1106 (2006).
2. N. Joshi et al. Computer Vision, 2007. ICCV 2007. IEEE 11th International Conference, 1-8 (2007).
3. Y. Rivenson et al. Opt. Lett. **37**, 1757 (2012).
4. Y. Rivenson and A. Stern. Opt. Lett. **36**, 3365 (2011).
5. O. Katz et al. Nature Photon **6**, 549 (2012).

IMAGING THROUGH TURBID MEDIA

Seeing through Turbid Fluids: **A New Perspective in Microfluidics**

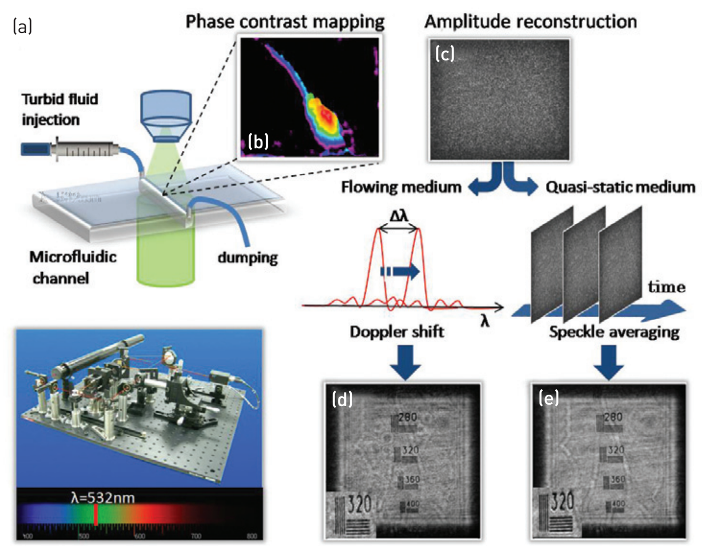
Optical imaging through turbid media has many potential uses, from homeland security to microscopic particle research. In 1967, Stetson conducted pioneering work on holography for imaging through scattering media. Years later, Lohmann et al. used holography to see through fog.[1] These studies and others have become more relevant since microfluidic technology and lab-on-chip devices were developed.[2,3]

Current imaging methods for microfluidic devices work only if the liquid is transparent, greatly limiting its use. Furthermore, media that start off clear often get turbid because of the chemical reactions that occur during the processes. We believe that digital holography (DH) could revolutionize microfluidic imaging because it provides clear amplitude and phase-contrast mapping of microscopic objects dipped into turbid liquid.

If a turbid colloidal solution flows at a velocity, v, the waves scattered by particles in the medium experience a Doppler frequency shift proportional to the medium velocity. If v exceeds a certain threshold, the waves do not contribute to the interference process with the reference wave or fringe formation.[1] In other words, the Doppler effect acts as a sort of spatial filter discarding the radiation that hits particles in the medium. With DH, only information from the static features on the observed object are recorded, producing clear amplitude and phase-contrast images.[4]

For quasi-static turbid media, the radiation scattered by the colloids superimpose coherently to the recording device resulting in speckle-noise, which strongly degrades image quality. Nevertheless, the Brownian motion of particles in the medium can be exploited to acquire uncorrelated images for incoherent processing. Thus, researchers can embrace a different strategy for quasi-static flow based on the acquisition of many images, allowing them a clear view through a turbid microfluidic channel without losing image resolution. If multiple images are properly selected, only a few are needed to get in the quasi-static case performance comparable to the dynamic flow case.[5]

Our investigations prove that scattering turbid media, in static and dynamic cases, does not impair imaging in a turbid microfluidic environment. DH technology provides the best imaging capabilities for the newest cutting-edge applications in microfluidics. OPN



(a) Experimental set-up. (Top) microfluidic chip, where a motorized piston is used to inlet a turbid fluid at tunable velocity. (Bottom) Mach-Zehnder interferometer. (b) Phase contrast mapping of bovine spermatozoa dipped into a turbid microfluidic channel after multi-look processing (v=0 μm/s). (c) Amplitude imaging by DH of a test target in turbid fluid at v=0 μm/s. (d) Reconstruction in case of fluid flowing at v=330 μm/s. (e) Reconstruction in case of quasi-static fluid (v=30 μm/s) after multi-look processing.

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References

1. A.W. Lohmann and C.A. Shuman. J. Opt. Soc. Am., **57**, 1060 (1967).
2. G. Indebetouw. Opt. Comm. **40**, 91 (1981).
3. P. Ronald. **4**, 022811 (2010).
4. M. Paturzo et al. Lab Chip **12**, 3073 (2012).
5. V. Bianco et al. Opt. Lett. **20**, 4212 (2012).