Deciphering speckle

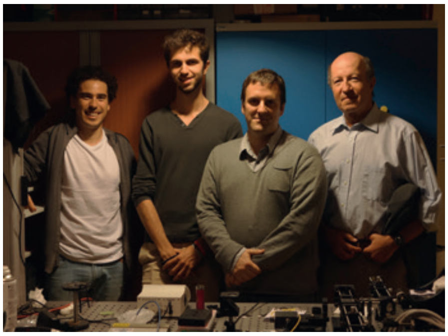
Ori Katz and Sylvain Gigan explain to *Nature Photonics* how a well-known astronomy technique has been adapted for imaging through turbid media, with great potential for bio-imaging applications.

What are the principles on which your technique is based?

Our experiment is inspired by a quite old astronomical imaging technique, invented in the 1970s by Antoine Labeyrie, called stellar speckle interferometry. It allows one to obtain diffraction-limited images of stars through the Earth's atmosphere. The image of any object gets smeared after passing through a scattering medium; all we see is a halo much larger than the image of the object. Although to our eyes this halo contains no information, useful information is hidden in the small spatial intensity fluctuations inside it. The reason is that although scattered light forms random patterns, the light from two nearby points is scattered to give a similar, almost identical speckle pattern, which is known as the optical memory effect, or isoplanatism. As they described in a 2012 *Nature* Letter, the group of Allard Mosk, at the University of Twente in The Netherlands, exploited these correlations to scan such scattered speckle patterns to retrieve images of hidden objects (*Nature* **491,** 232–234; 2012). Inspired by their results and Labeyrie's technique, we did the opposite experiment (which proved to be a very simple one). Instead of scanning the illuminating beam, we took a single image with a conventional camera. As every pixel looks at the light coming from the object from a different angle, we could get the same information you'd get from a long scan with just a single camera click. Surprisingly enough, analysing the correlations of this single camera frame provides a fast and efficient method for imaging through turbid media.

What was the motivation for your work?

We did this experiment for two reasons. First of all, to satisfy the curiosity of an optical physicist: it is quite counterintuitive that a blurry image of a diffuse halo contains any information about the hidden object itself. Showing that a visually opaque layer can be made 'transparent' in a very simple way is interesting and exciting. The second reason is the development of biomedical imaging related applications, which was why we conducted some experiments using chicken breast as the scattering medium. We imaged small objects through half-millimetre layers of tissue, which is a first step. We hope our technique could be — following improvements — useful for biomedical (and probably also defence related) imaging, providing an alternative to the invasive procedures currently used. At the end of the day, science is meant to make a difference in people's lives and we would very much like to achieve that.



LKB/INSTITUT LANGEVIN

Ori Katz, Pierre Heidmann, Sylvain Gigan and Mathias Fink at the Institut Langevin and Laboratoire Kastler Brossel in Paris, France, have demonstrated non-invasive single-shot imaging of small objects behind turbid media using speckle correlations.

What is the significance?

Our work will hopefully provide a more realistic technique for imaging through constantly evolving turbid media. It is not affected by the temporal evolution of the medium itself as much as other approaches, where the procedure has to be performed much faster than the evolution timescale of the medium. In wavefront shaping approaches, for example, the focus configuration ceases to be valid as soon as the medium undergoes a change. The main feature of our experiment is that neither the characterization of the medium nor its evolution is a problem anymore, provided one has enough signal.

What was the biggest experimental challenge?

Taking the raw images was pretty straightforward as long as some simple precautions about the size of the speckles or the camera's position were taken. The reconstruction algorithm itself proved to be more demanding. Although we are using it in a very basic form, finding the correct parameters and making it work reliably on our experimental data was the biggest challenge in this experiment. It is a very basic phase retrieval algorithm — pioneered in the 1980s by James Fienup. It is basically a modified Gerchberg–Saxton algorithm that tries to retrieve the object from its autocorrelation. Knowing that our object is real, positive and fairly small, there should be only a single solution to the problem. The downside of such an iterative algorithm is that sometimes it gets stuck in local minima. At the end, the reconstructions presented in our Article were retrieved by brute force: we simply ran the algorithm about a hundred times with different initial conditions and finally chose the solution where the autocorrelation was the closest to the one we measured.

Your work implies that nothing is hidden anymore! Are we still safely hidden behind the shower curtain?

Most probably yes. Our technique is effective only for imaging small objects behind thin layers as the range of the memory effect that we exploit becomes smaller as the medium becomes thicker. With the chicken and onion samples that we used it was still present but limited, whereas it should barely be there for thicknesses greater than a centimetre. Also, our technique works better with narrowband illumination; to use it with natural light one needs to use a narrow bandpass filter, which would decrease the signal dramatically. As a result, a better camera and longer integration times would be needed, and the method would not be as practical. Although we now know that the light scattered off a white wall can contain a lot of information (and for reflection the memory effect can be quite large and is independent of the wall thickness), there are still major improvements to be made before imaging bigger objects under real-life conditions.

INTERVIEW BY MARIA MARAGKOU

Ori Katz and co-workers have an Article on non-invasive imaging behind scattering layers on page 784 of this issue.