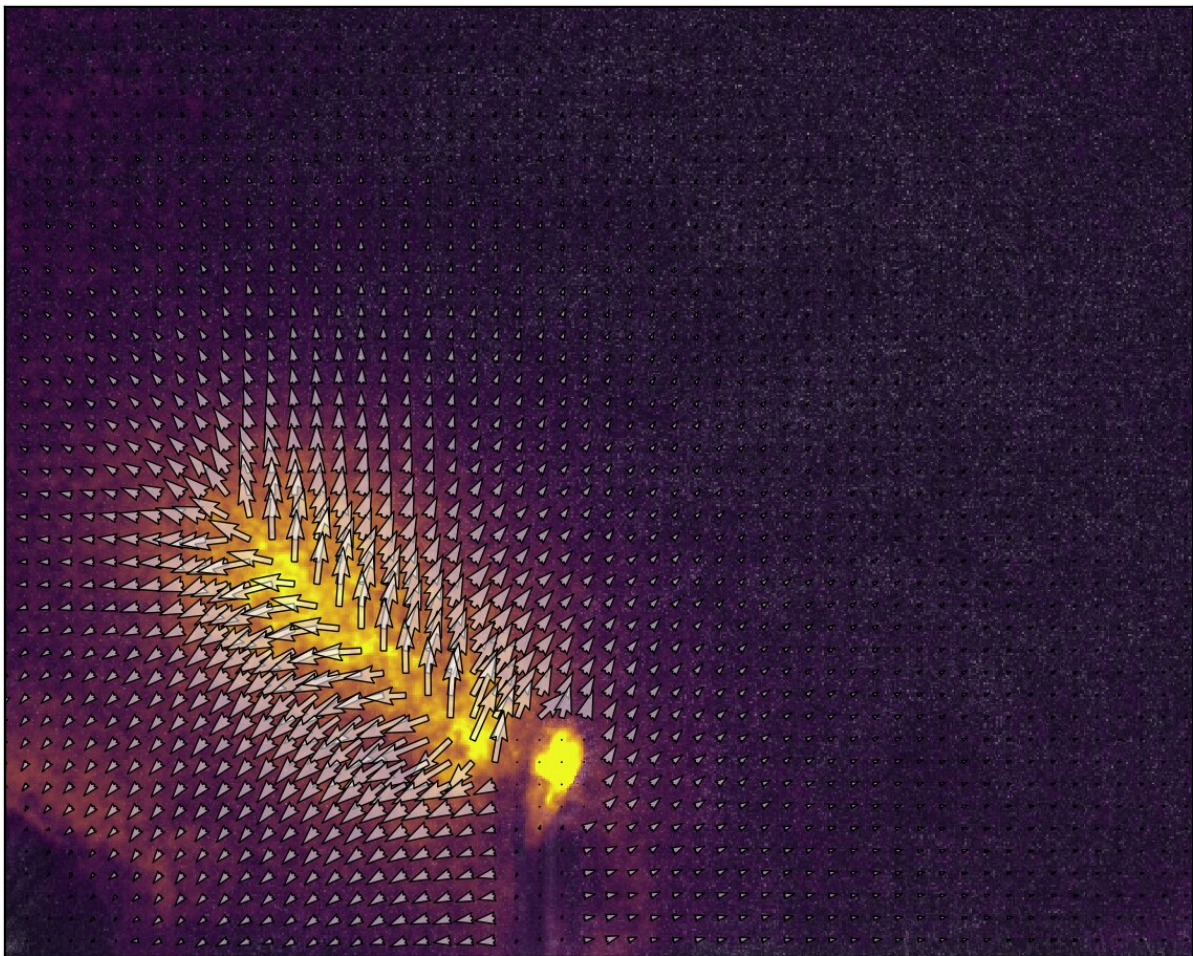


Dynamic speckle holography: A highly effective optical technique that combines imaging and scattering

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Credit: Aime et al.

Researchers at Harvard University and China University of Petroleum recently developed dynamic speckle holography (DSH), a new technique to measure three-dimensional (3D) maps of displacements that combines imaging and scattering approaches. This technique, presented in a paper published in *Physical Review Letters*, can detect displacements as small as 10 nanometers over several centimeters, thus significantly outperforming conventional imaging techniques.

"DSH was born in the Weitzlab at Harvard, where I did my postdoc between 2018 and 2020," Stefano Aime, the principal investigator for the study, told Tech Xplore. "One of my post-doctoral projects was about fracture propagation in porous media, which fascinated me even though it was quite distant from my scientific background. As an outsider, I started watching other people's experiments and wondering what exactly was driving the crack, what dictated its direction and speed, what happened close to a boundary or a defect, and similar questions."

When Aime started researching fracture propagation, his academic supervisor Dave Weitz encouraged him to trust his curiosity and conduct his own experiments, rather than merely seeking for answers in existing literature. After he gained a good understanding of [light](#) scattering, he thus started experimenting with different techniques and approaches.

"One day I decided to aim a laser at the cracking sample and record a video of the scattered light," Aime explained. "The optical setup I employed was identical to photon correlation imaging, so nothing particularly new in itself. However, the result was surprising. What I found was a funny butterfly-like pattern, which moved with the crack tip and extended deep into the material, far away from the crack, where no motion at all could be observed even under a microscope. I had no idea of what that signal was, but I thought it was cute and worth investigating."

During his experiments, Aime realized that the signal he observed was a generalization of another phenomenon he studied during his Ph.D., namely the signal arising from the elastic deformation of a sample projected onto the scattering vector. This realization inspired him to develop a new technique that uses two lasers and two cameras to measure a sample's full 3D deformation field. Using the technique he developed, Aime was able to learn far more about fracture propagation than what he would have learned if he had merely reviewed existing literature.

"Illumination by laser light always gives a very different picture as compared to regular light," Lizhi Xiao, another researcher involved in the study, told Tech Xplore. "This is because the coherence of the laser light and some small features can produce bright spots that twinkles. It was exciting to realize that such twinkles (or speckles) can be combined with imaging to achieve DSH to observe the minute strains and their propagation."

Holography is a technique that aims at reconstructing the full shape of a 3D object from 2D images of it. The idea behind DSH is similar: each scattering vector (i.e. combination of incoming laser beam + diaphragm/lens/camera) allows one to probe one projection of the displacement field.

"We reconstruct the full, three-dimensional displacement field by combining information obtained with different scattering vectors (4 combinations of 2 incoming laser beams and 2 sets of collection optics)," Aime said. "That's what makes DSH an holographic technique. Not in the standard sense (it doesn't reconstruct any 3D object), but in a generalized sense (it reconstructs 3D displacement fields)."

When using conventional holography, the surfaces of the examined objects reflect the laser light. However, when an object is transparent,

such as water or clear plastic, the light that arrives at the detector will only come from the laser's reflection off particles or cracked surfaces. The size of these reflections can be very small and impossible to detect using conventional microscopes.

"When such small features move a distance comparable to the wavelength of the light, the interference pattern may change and thus translate the movement to light intensity," Xiao said. "One may think of DSH, the technique developed by Stefano, as a very sensitive transducer to convert mechanical movement/strain to light."

DSH combines imaging and scattering to create 3D maps of displacements as small as ten nanometers over fields of view as large as several centimeters. To achieve this, Aime's technique correlates images of the speckle patterns of [laser light](#) scattered by the examined sample.

"The decay in the temporal correlation can be converted into sub-micron local motion, whose magnitude and direction can be precisely reconstructed by exploiting simultaneous illumination from three laser sources," Aime said. "Because DSH relies on interference to probe motion, it is sensitive to much smaller displacements than any other imaging technique, as these methods all rely on detecting motion of features in the image."

The primary advantages of the technique developed by Aime and his colleagues are its high sensitivity and large field of view. These two characteristics allow DHS to significantly outperform traditional imaging systems, opening up new exciting possibilities for the study of a number of physical phenomena characterized by minute motion correlated over macroscopic distances, including fluid-flow and mechanical instabilities.

"Stefano's observation of fracture propagation using the technique he developed is amazing," Xiao said. "The phenomenon of fracturing

occurs in so many fields and has many applications. However, it is in fact very difficult to study fracturing process in materials because most real materials are opaque to light."

Fracture propagation (i.e., the physical propagation of cracks across materials or objects) can occur very quickly in hard materials. How quickly fractures propagate can also depend on several properties of a material, such as heterogeneity, bedding plane, confining pressure, internal strains, fluid pore pressure and permeability. The study of fractures in geological materials is of crucial both for geoscience research and industrial production.

The new technique developed by Aime already led to a better understanding of fracture propagation. In the future, it could be used by other teams worldwide to investigate fracture mechanisms in hard and porous materials further.

"This work is just the beginning, as there are plenty of DSH experiments we could conduct on fractures propagating in heterogeneous environments, which we are currently analyzing, to learn something new," Aime said. "One year ago, I moved to Paris, where I have new projects starting, once again in a different direction. Yet, most of my post-doctoral projects are still ongoing: they're too much fun to be just left behind. And I believe the best is yet to come!"

More information: S. Aime et al, Dynamic Speckle Holography, *Physical Review Letters* (2021). [DOI: 10.1103/PhysRevLett.127.088003](https://doi.org/10.1103/PhysRevLett.127.088003)

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