Physics

VIEWPOINT

Ghost Imaging with X Rays

The technique of ghost imaging, which builds up images of objects by combining information from light collected at two detectors, has been demonstrated in the x-ray regime.

by Dilano Saldin*

Conventional imaging methods capture an image of an object by recording, in a multipixel detector, the intensity and color of a light beam that hits the object. The technique of ghost imaging is different. It forms an image of the object using correlations between the intensities of two light beams, an "object beam" that strikes the object and a "reference beam" that does not. Crucially, in this form of imaging, the object doesn't have to receive a high dose of radiation. But so far, ghost imaging has only been demonstrated with visible and infrared light. Two new studies, by Daniele Pelliccia from RMIT University, Australia, and colleagues [1] and by Hong Yu from the Chinese Academy of Sciences, Shanghai, and co-workers [2], now extend this imaging capability to the x-ray regime. This wavelength domain is widely used in medical imaging, so the approach could pave the way to reducing the damage incurred by radiation exposure in such imaging.

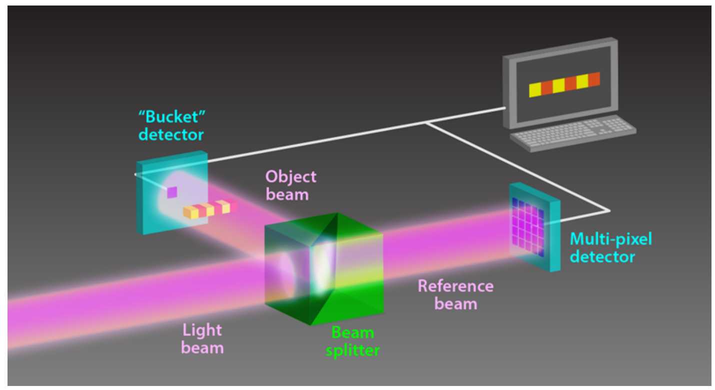

Figure 1: In the method of ghost imaging, an object is imaged using correlations, analyzed computationally, between the intensities of two light beams: an "object beam" that hits the object and reaches a single-pixel ("bucket") detector, and a "reference beam" that does not hit the object and arrives at a multipixel detector. Pelliccia *et al.* [1] and Yu *et al.* [2] demonstrate ghost imaging in the x-ray regime. (APS/Alan Stonebraker)

Correlations between intensities, rather than between amplitudes, were first used in the 1950s by astronomers Robert Hanbury Brown and Richard Twiss to measure the apparent diameters of distant stars [3]. The researchers showed that intensity correlations between starlight from the same source, received at two detectors separated by a given distance, carry information about the difference between the phases of the starlight that reaches each detector, even though only intensities are measured. This phase difference allows the apparent diameter of a star to be determined. The effect has since found fruition in a number of fields, including in optics (see, for example, Ref. [4]) and x-ray imaging and spectroscopy. For example, x-ray photon correlation spectroscopy [5] makes use of intensity correlations to determine the spatial distribution of matter on the time scale at which atomic motion takes place. Another approach utilizing intensity correlations is x-ray free-electron laser (XFEL) imaging. Here, intensity correlations between two XFEL beams are measured to obtain the individual structures of randomly oriented particles, such as biological molecules, in a large ensemble [6]. However, the technique entails running computational algorithms to derive the structures that are often very sensitive to missing data. These data are associated with gaps in the detector panels or strong beam intensities that are blocked from detection to avoid damaging detectors.

Compared to conventional imaging, ghost imaging stands out in two main ways. First, it works with a weak (few photons) object beam if the reference beam is strong. The resulting intensity correlations between the beams can still generate a good-quality image of the object; traditional low-dose imaging methods generate noisy images. Second, it is robust against atmospheric turbulence. The approach is being actively studied for ground-based imaging of satellites through atmospheric turbulence and clouds and for remote sensing. Turbulence produces random scattering of light, blurring images that are acquired using traditional methods. But ghost imaging is immune to it because random scattering is averaged out in the process; only the intensity correlations between the object beam and the reference beam are retained.

The techniques that Pelliccia and colleagues and Yu and co-workers use to demonstrate ghost imaging in the x-ray domain are similar to their optical counterparts. They gen-

*Department of Physics, University of Wisconsin-Milwaukee, Milwaukee, WI 53201, USA

erate an image of the object using a computer analysis of correlations between the intensity of the object beam, which is directed to a single-pixel ("bucket") detector, and the intensity of the reference beam, which travels to a multipixel detector (Fig. 1). However, they differ from one another in some aspects. For example, whereas Yu and co-workers' imaging data are acquired in Fourier space, Pelliccia and colleagues' data are obtained directly in real space.

Other than their possible application to medical imaging, it would be interesting to see whether the methods could offer the means to tackle what has become known in the field of x-ray diffraction imaging as the phase problem [7, 8].This refers to the fact that conventional detectors cannot directly measure the phase of the x-ray beam that diffracts from the object; the phase has to be determined using computational approaches. But there is some hope of measuring the phase directly in x-ray diffraction imaging by borrowing concepts from holography and from the techniques proposed here, especially Yu and co-workers' technique. In holography, the interference pattern between an object beam and a reference beam carries information about the amplitude as well as the phase of the beams, even though the detector used to record the pattern is sensitive only to the amplitudes. This is done at the price of generating a so-called twin image of the object, which later has to be suppressed. If this idea could be applied to the authors' methods, which also rely on detectors that are sensitive only to the amplitudes, it could potentially solve the phase problem; there are details that remain to be worked out. Stay tuned for further developments on this front.

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