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Researchers develop high-resolution technique for non-invasively imaging hidden layers in centuries-old paintings

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After Raphael 1483 - 1520; probably before 1600; Oil on wood; 87 x 61.3 cm; Wynn Ellis Bequest, 1876. Credit: (c) National Gallery, London

A painting hanging on the wall in an art gallery tells one story. What lies beneath its surface may tell quite another.

Often in a Rembrandt, a Vermeer, a Leonardo, a Van Eyck, or any other great masterpiece of western art, the layers of paint are covered with varnish, sometimes several coats applied at different times over their history. The varnish was originally applied to protect the paint underneath and make the colors appear more vivid, but over the centuries it can degrade. Conservators carefully clean off the old varnish and replace it with new, but to do this safely it is useful to understand the materials and structure of the painting beneath the surface. Conservation scientists can glean this information by analyzing the hidden layers of paint and varnish.

Now, researchers from Nottingham Trent University's School of Science and Technology have partnered with the National Gallery in London to develop an instrument capable of non-invasively capturing subsurface details from artwork at a high resolution. Their setup, published in an *Optics Express* paper, will allow conservators and conservation scientists to more effectively peek beneath the surface of paintings and artifacts to learn not only how the artist built up the original composition, but also what coatings have been applied to it over the years.

Traditionally, analyzing the layers of a painting requires taking a very small physical sample—usually around a quarter of a millimeter across—to view under a microscope. The technique provides a crosssection of the painting's layers, which can be imaged at high resolution and analyzed to gain detailed information on the chemical composition of the paint, but does involve removing some original paint, even if only a very tiny amount. When studying valuable masterpieces, conservation scientists must therefore sample very selectively from already-damaged areas, often only taking a few minute samples from a large canvas.

More recently, researchers have begun to use non-invasive imaging techniques to study paintings and other historical artifacts. For example, Optical Coherence Tomography (OCT) was originally developed for medical imaging but has also been applied to art conservation. Because it uses a beam of light to scan the intact painting without removing physical samples, OCT allows researchers to analyze the painting more extensively. However, the spatial resolution of commercially-available OCT setups is not high enough to fully map the fine layers of paint and varnish.

The Nottingham Trent University researchers gave OCT an upgrade. "We're trying to see how far we can go with non-invasive techniques. We wanted to reach the kind of resolution that conventional destructive techniques have reached," explained Haida Liang, who led the project.

In OCT, a beam of light is split: half is directed towards the sample, and the other half is sent to a reference mirror. The light scatters off both of these surfaces. By measuring the combined signal, which effectively compares the returned light from the sample versus the reference, the apparatus can determine how far into the sample the light penetrated. By repeating this procedure many times across an area, researchers can build up a cross-sectional map of the painting.

Liang and her colleagues used a broadband laser-like light source—a concentrated beam of light containing a wide range of frequencies. The wider frequency range allows for more precise data collection, but such light sources were not commercially available until recently.

Along with a few other modifications, the addition of the broadband light source enabled the apparatus to scan the painting at a higher resolution. When tested on a late 16th-century copy of a Raphael painting, housed at the National Gallery in London, it performed as well as traditional invasive imaging techniques.

"We are able to not only match the resolution but also to see some of the layer structures with better contrast. That's because OCT is particularly sensitive to changes in refractive index," said Liang. In some places, the ultra-high resolution OCT setup identified varnish layers that were almost indistinguishable from each other under the microscope.

Eventually, the researchers plan to make their instrument available to other art institutions. It could also be useful for analyzing historical manuscripts, which cannot be physically sampled in the same way that paintings can.

In a parallel paper recently published in *Optics Express*, the researchers also improved the depth into the painting that their apparatus can scan. The two goals are somewhat at odds: using a longer wavelength light source could enhance the penetration depth, but shorter wavelength light (as used in their current setup) provides the best resolution.

"The next challenge is perhaps to be able to do that in one instrument, as well as to extract chemical information from different layers," said Liang.

More information: "Ultra-high resolution Fourier domain optical coherence tomography for old master paintings," C.S. Cheung et al., *Optics Express*, Vol. 23, Issue 8, pp. 10145-10157 (2015).
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