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Optical coherence tomography holds promise for conserving art

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Optical coherence tomography (OCT) has migrated successfully from medical imaging to materials science, where it is used online to monitor varnish removal from paintings.

Noninvasive examinations of human patients and art objects share more than the important modus operandi of 'do no harm.' Soon after medical x-rays were discovered, they were applied to inspect the underlying layers of paintings. More recently, that extended to the newer modality of x-ray tomography. Now, optical coherence tomography (OCT), which acquires and processes optical signals to produce high-quality 3D images, has entered the picture. Medical OCT was first described in 1991,[1] and reports of its use to examine artwork[2–4] emerged in 2004.

OCT uses low-coherence interferometry, a tool to study lightwave properties, to determine the distance to the scattering center in an object that moderately absorbs light. The light source's spectral width determines the localization precision: IR broadband light sources spanning 200nm allow for better than 2μm axial resolution. While this is still less than in phase interferometry, the result is free of the phase-ambiguity disadvantages that limit the height difference between two adjacent data points. The most popular interferometer configuration is Michelson's type (see Figure 1), in which scattering-center positions are recovered from interference-fringe frequencies superimposed on the light sources' spectra.

In our conservation experiment, we used a home-grown instrument[5] with 4μm axial resolution at a central wavelength of $\lambda = 850$nm, shown in Figure 1. The results were obtained with two CCD linear cameras: an Action Research 2048-pixel, 12-bit resolution model and a Dalsa Corp. 1024-pixel, 8-bit resolution, high-transfer camera. The former is used when high sensitivity and imaging depth are required, and the latter for fast, real-time imaging (two frames of 400 lines per second) for monitoring conservation treatments.

An interesting example of a process requiring online monitoring is laser ablation to remove varnish.[6] If varnish is dull or yellowed, it must be removed to conserve the art work's paint. Laser ablation is a good alternative when the varnish layer is more resistant than the underlying paint, thus making classic chemical and/or mechanical removal difficult. In contrast to

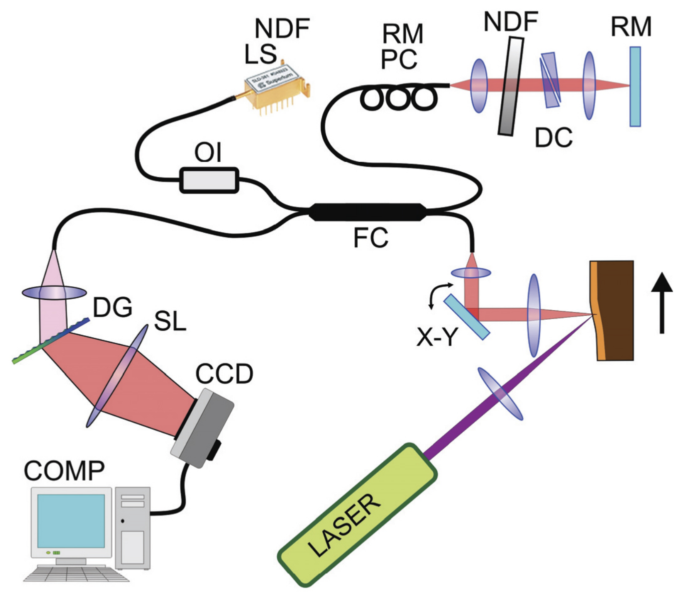

Figure 1. *Experimental laser/interferometer artwork-conservation treatment setup. The optical isolator (OI) is inserted between the light source (LS) and the fiber coupler (FC) to protect the former from reflected light. Light passes through the coupler and then propagates in the interferometer's reference and object arms. In the reference arm (top right), it passes through the polarization controller (PC), a neutral-density filter (NDF), the dispersion compensator (DC), and is then back-reflected by the stationary reference mirror (RM). In the object arm, comprised of transversal scanners (X-Y) and a lens, the light beam is scanned across the object and then backscatters. The returning light from both arms is collected and then analyzed using a spectrometer consisting of the spectrograph lens (SL), diffraction grating (DG), CCD linear camera, and a personal computer (COMP).*

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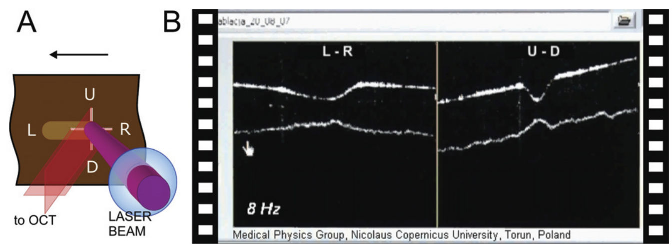

Figure 2. (a) In an experimental configuration, the white cross—left (L), right (R), up (U), and down (D)—shows locations of scanning planes for the OCT movie. (b) Movie frame[8] taken during the ablation experiment. The strong top line on the tomograms is the varnish surface. The line underneath is the varnish/paint-layer interface.

well-established laser cleaning of stones,[7] in which dark crust ablation from white stone is self-terminated, varnish ablation requires an effective way to monitor the remaining lacquer layer's thickness. We have found that OCT can be used for both real-time monitoring and post-process inspection.

During our ablation experiment, a varnish layer was partially removed from the test sample with an Nd:YAG (neodymium-doped yttrium aluminum garnet) laser generating 10ns UV pulses ($\lambda = 266$nm) at frequencies from 2 to 10Hz. To demonstrate OCT real-time monitoring ability, a video[8] was taken with an ordinary camera from our OCT system's monitor. The movie (see Figure 2) shows tomograms of cross sections in two directions: left-right (parallel to the groove ablated in the varnish layer) and up-down (perpendicular to the groove). The strong top line on the tomograms is the varnish surface. The line underneath is the varnish/paint-layer interface. The apparent line elevation is caused by refraction: in OCT images, all in-depth distances are optical.

OCT was used for static, high-resolution imaging (see Figure 3) to inspect the ablation process quality. An IR Er:YAG (erbium:YAG) laser ($\lambda = 2.936\mu$m) was also used. The absorption by the varnish layer was not sufficient to limit heat dissipation to the surface layer, so the interaction of the laser pulse with the paint layer created unwanted exfoliation.

OCT control may make ablation safer for artwork. However, before it is introduced for routine use in conservation, we must confirm that it is safe. We must also consider the long-term photochemical and thermal impact of laser radiation. Nevertheless, a similar approach may be applied to other kinds of laser processing if the treated medium is transparent enough to be visualized with near-IR radiation.

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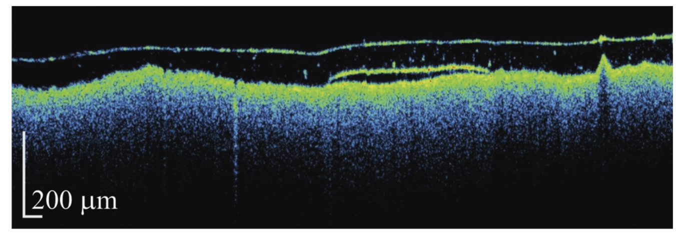

Figure 3. OCT tomogram of an exfoliated varnish layer caused by incorrect ablation conditions.

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Piotr Targowski, professor, received his PhD and DrHabil from the Nicolaus Copernicus University. His current research focuses on using spectral-domain OCT to investigate the structure and some properties of museum objects. He is a member of the Polish Photonic and Physical Societies.

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Bogumila J. Rouba is professor and chair of the Painting Conservation Division. Her current research focus is on conservation of mural paintings and oil paintings on canvas, as well as sustainability of the cultural heritage in the face of environmental hazards.

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8. Video taken directly from the screen of the OCT tomograph during monitoring of laser ablation of Dammar Matt Varnish.
http://spie.org/documents/newsroom/videos/1589/Fig2.avi