Researchers achieve meter-scale optical coherence tomography for first time

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A new 3-D OCT technique allows imaging of large objects such as this life-size mannequin and chessboard. Credit: James G. Fujimoto, Massachusetts Institute of Technology

An industry-academic collaboration has achieved the first optical coherence tomography (OCT) images of cubic meter volumes. With OCT's ability to provide difficult-to-obtain information on material composition, subsurface structure, coatings, surface roughness and other properties, this advance could open up many new uses for OCT in industry, manufacturing and medicine. The achievement also represents important progress toward developing a high-speed, low-cost OCT system on a single integrated circuit chip.

"Our study demonstrates world-record results in cubic meter volume imaging, with at least an order of magnitude larger depth range and volume compared to previous demonstrations of three-dimensional OCT," said James G. Fujimoto of the Massachusetts Institute of Technology (MIT), Massachusetts. "These results provide a proof-of-principle demonstration for using OCT in this new regime."

OCT, first invented by Fujimoto's group and collaborators in the 1990s, is now the standard of care in ophthalmology and is increasingly used in cardiology and gastroenterology. Although OCT provides useful 3-D images with micron-scale resolution, it has been limited to imaging depths of just millimeters to a few centimeters.

In The Optical Society's journal for high impact research, *Optica*, the researchers report high speed, 3-D OCT imaging with 15-micron resolution over a 1.5-meter area. They demonstrated the new OCT approach by imaging a mannequin, a bicycle and models of a human brain and skull. They also conducted measurements of objects ranging in scale from meters to microns.

Multiple scales over long ranges

In addition to the advantages of high speeds and fine resolution, OCT enables imaging, profiling and distance measurement at multiple depths simultaneously while rejecting stray light.

"Long-range OCT is a new range of operation that requires extremely high performance light sources, integrated optical receivers and signal processing," Fujimoto said. Range in OCT refers to the depth range over which measurements can be simultaneously taken. It is possible to position the center of the OCT range very close to or far away from the imaging instrument.

The new technique could be particularly useful for industrial and manufacturing settings, where it could potentially be used to monitor processes, take technical measurements and nondestructively evaluate materials. Macro-scale OCT could also enhance medical imaging, for example, by providing three-dimensional measurements in laparoscopy or mapping structures such as the upper airway.

Telecom advances bring OCT improvements

The light source that enables meter-range OCT is a tunable vertical cavity surface-emitting laser (VCSEL) developed by Thorlabs Inc. and Praevium Research. It uses a MEMS device to rapidly change, or sweep, the laser's wavelength over time to perform what is called swept-source OCT.

"Research by our group at MIT and our collaborators at Praevium Research and Thorlabs indicated that the coherence length of the VCSEL source was orders of magnitude longer than other swept laser technologies suitable for OCT, which suggested the possibility of long-range OCT imaging," said Ben Potsaid of MIT and Thorlabs Inc., coauthor of the paper.

Although the MIT researchers have experimented with the VCSEL light source for several years, light detection and data acquisition remained a challenge. These hurdles were overcome by advanced optical components designed for telecommunications applications.

In the new work, the researchers used a new silicon photonics coherent optical receiver developed by Acacia Communications that replaced several bulky OCT components with integrated optics on a tiny, low-cost, single-chip photonic integrated circuit (PIC). Importantly, the PIC receiver supports the very high electrical frequencies and wide range of optical wavelengths required for swept-source OCT while also enabling what is known as quadrature detection, which doubles the OCT imaging range for a given data acquisition speed.

"The development of OCT in the early 1990s greatly benefited from components and methods used in fiber optical communications," said Fujimoto. "And still, 25 years later, advances in the optical communications industry continue to greatly benefit OCT."

In the paper, the researchers showed that meter-range OCT can obtain a strong signal from surfaces of varying geometry and materials. Their tests also indicated the technique's performance has not reached the fundamental limits for the VCSEL laser source or PIC receiver.

OCT-on-a-chip

The researchers are working to develop and utilize even more low-cost, high-speed components with the goal of speeding up the data acquisition and processing steps. This could eventually allow real-time OCT imaging using customized integrated circuit chips.

"As PIC technology continues to advance, one can realistically expect full OCT systems on a single chip within the next five years, dramatically lowering the size and cost," said Chris Doerr of Acacia Communications, coauthor of the paper. "This would allow more people all over the world to benefit from OCT and open up new applications."

More information: Zhao Wang et al, Cubic meter volume optical coherence tomography, *Optica* (2016). DOI: 10.1364/optica.3.001496

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