Quantum lidar prototype acquires real-time 3D images while fully submerged underwater

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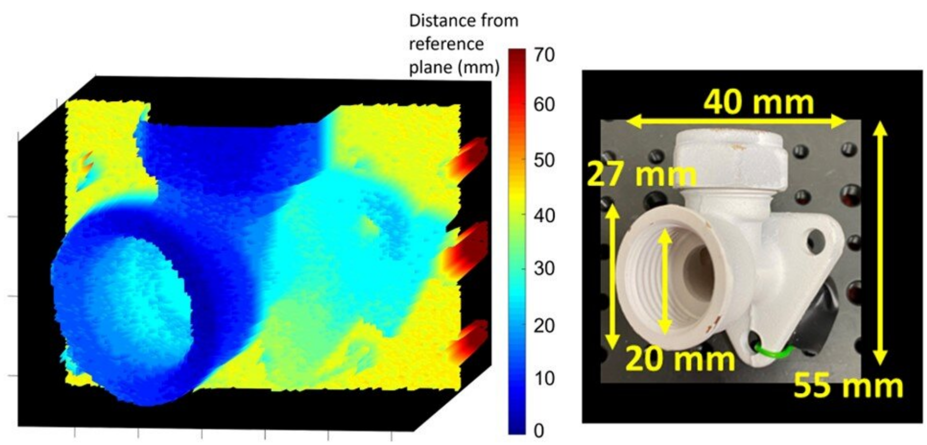

Researchers developed a lidar system that uses quantum detection technology that can capture 3D images while submerged underwater. They demonstrated the system by using it to capture a 3D image (left) of a pipe (right). The scan was obtained in low scattering conditions with the single-photon system submerged in a tank. Credit: Aurora Maccarone, Heriot-Watt University

For the first time, researchers have demonstrated a prototype lidar system that uses quantum detection technology to acquire 3D images while submerged underwater. The high sensitivity of this system could allow it to capture detailed information even in extremely low-light conditions found underwater.

"This technology could be useful for a wide range of applications," said research team member Aurora Maccarone, a Royal Academy of Engineering research fellow from Heriot-Watt University in the United Kingdom. "For example, it could be used to inspect underwater installations, such as underwater wind farm cables and the submerged structure of the turbines. Underwater lidar can also be used for monitoring or surveying submerged archaeology sites and for security and defense applications."

Obtaining 3D images through ocean water can be challenging because it is light-limited, and any particles in the water will scatter light and distort the image. However, single-photon detection, which is a quantum-based technique, allows very high penetration and works even in low-light conditions.

In *Optics Express*, researchers from Heriot-Watt University and the University of Edinburgh describe experiments in which an entire single-photon lidar system was submerged in a large water tank. The new demonstrations bring the technology closer to practical applications compared to the research team's earlier experiments with underwater single-photon detection, which were performed in carefully controlled laboratory conditions with the optical setup placed outside the water tank and data analysis performed offline.

They also implemented new hardware and software developments that allow the 3D images acquired by the system to be reconstructed in real time.

"This work aims to make quantum detection technologies available for underwater applications, which means that we will be able to image the scene of interest in very low light conditions," said Maccarone. "This will impact the use of offshore cable and energy installations, which are used by everyone. This technology could also allow monitoring without the presence of humans, which would mean less pollution and a less invasive presence in the marine environment."

Faster low-light detection

Lidar systems create images by measuring how long it takes laser light to be reflected from objects in the scene and travel back to the system's receiver, known as the "time of flight." In the new work, the researchers sought to develop a way to acquire 3D images of targets that are obscured by turbid water and thus not visible to conventional lidar imaging systems.

They designed a lidar system that uses a green pulsed laser source to illuminate the scene of interest. The reflected pulsed illumination is detected by an array of single-photon detectors, which allows ultrafast low light detection and greatly reduces measurement time in photon-starved environments such as highly attenuating water.

"By taking time-of-flight measurements with picosecond timing resolution, we can routinely resolve millimeter details of the targets in the scene," said Maccarone. "Our approach also allows us to distinguish the photons reflected by the target from those reflected by particles in the water, making it particularly suitable to performing 3D imaging in highly turbid waters where optical scattering can ruin image contrast and resolution."

The fact that this approach requires thousands of single-photon detectors, all producing many hundreds of events per second, makes it extremely challenging to retrieve and process the data necessary to reconstruct the 3D image in a short time, especially for real-time applications. To solve this problem, the researchers developed algorithms specifically for imaging in highly scattering conditions and applied them in conjunction with widely available graphics processing unit (GPU) hardware.

The new technique builds on some important technological advances. "Heriot-Watt University has a long track record in single-photon detection techniques and image processing of single-photon data, which allowed us to demonstrate advanced single-photon imaging in extremely challenging conditions," said Maccarone.

"The University of Edinburgh has achieved fundamental advances in the design and fabrication of single-photon avalanche diode detector arrays, which allowed us to build compact and robust imaging systems based on quantum detection technologies."

Underwater testing

After optimizing the optical setup on a laboratory optical bench, the researchers connected the lidar system to a GPU to achieve real-time processing of the data while also implementing a number of image processing approaches for three-dimensional imaging. Once the system was working properly, they moved it to a tank that was 4 meters long, 3 meters wide, and 2 meters deep.

With the system submerged in the water, the researchers added a scattering agent in a controlled manner to make the water more turbid. Experiments at three different turbidity levels demonstrated successful imaging in controlled highly scattering scenarios at distances of 3 meters.

"Single-photon technologies are rapidly developing, and we have demonstrated very promising results in underwater environments," said

Maccarone. "The approach and image processing algorithms could also be used in a wider range of scenarios for improved vision in free space such as in fog, smoke or other obscurants."

The researchers are now working to reduce the size of the system so that it could be integrated into an underwater vehicle. Through the UK Quantum Technology Hub Network and InnovateUK, the researchers are partnering with industry to make the technology accessible for a range of underwater applications.

More information: Aurora Maccarone et al, Submerged single-photon LiDAR imaging sensor used for real-time 3D scene reconstruction in scattering underwater environments, *Optics Express* (2023). [DOI: 10.1364/OE.487129](https://doi.org/10.1364/OE.487129)

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