Underwater Sonar and Laser Measuring
An Experimental Comparison

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Introduction

In underwater inspection, there is a need for sensors that can determine the structure of an asset. Usually represented as a 3D digital point cloud, these measurements are used for engineering calculations, maintenance planning, and ROV localization. The most prevalent technology in this field is sonar, and high frequency multi-beam sonar systems are capable of capturing complete 3D digital point-cloud representations of underwater environments. There are however physical limitations to the resolution capability of these technologies for understanding small yet important features of structures such as cracks and erosion in concrete structures or welds and dents in metallic marine infrastructure. Underwater laser scanners are not affected by the same physical principles as sonar and have the ability to capture details of underwater assets that were previously unobtainable.

Sonar Principles

Active sonar ranging is based on emitting a pulse of sound energy to a target surface and measuring the time taken for an echo to return. Based on the speed of sound in water, the distance to the target surface can be calculated. 3D sonar systems assume that the contact point is in the centre of the beam of sound energy when converting the return to a 3D point. Sound energy expands as it propagates through water, however, and a sonar pulse produces returns not only from the centre of the beam but also from any surface in its cone-shaped acoustic beam. The precision of sonar systems is limited because they must approximate a relatively large footprint area with a single point. Details such as cracks that are smaller than the footprint cannot be resolved, and sudden changes in structure such as edges cannot be located more precisely than the size of the footprint.

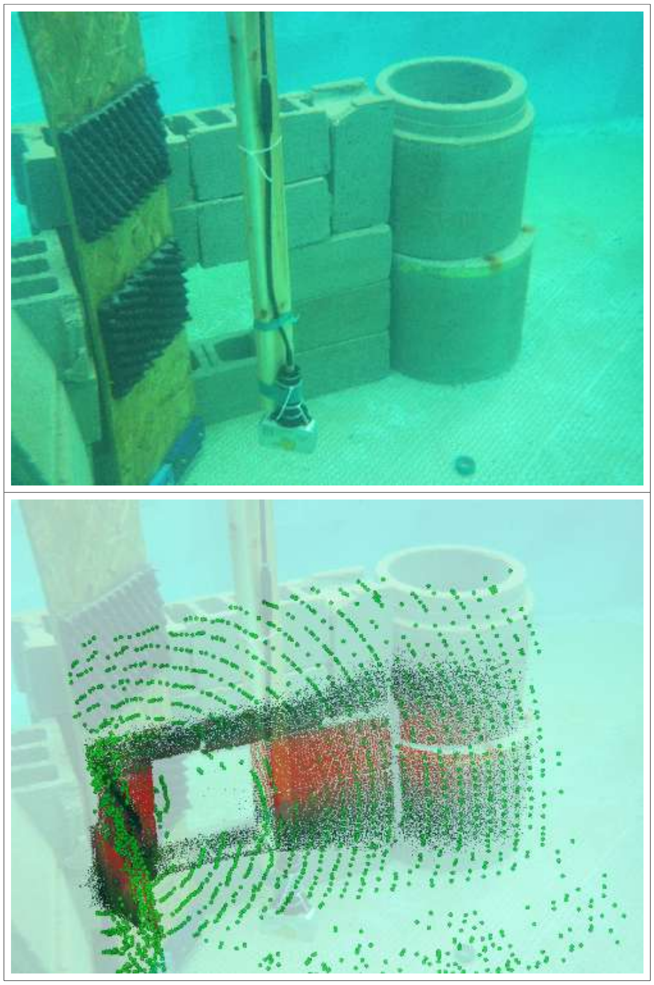

Figure 1: Underwater 3D Laser Scan Data and 3D Sonar Data Comparison - photo of test target.

Note: The wooden board shown in the photo was not present during scanning, and does not appear in the point clouds

To view an animation of the points for a better understanding of the structure,

Visit www.youtube.com/user/2grobotics

Laser Principles

Laser scanners are widely used in terrestrial applications for high resolution measurements. Light is not transmitted through water nearly as well as in air, and the effective range of laser systems drops from several kilometers in air to several meters in water. Traditional time-of-flight methods used by some terrestrial laser scanners are not effective at these short ranges – the time between laser pulse and return signal is too short to measure accurately. Short-range terrestrial laser scanners work around this limitation through signal processing (phased-intensity methods), however this method is not effective underwater due to the presence of silt.

Figure 2: 2G Robotics ULS-100

The 2G Robotics ULS-100 underwater laser scanner uses a trigonometric approach. The sensor head sends a laser line to the target surface, and an optical sensor captures the return signal. The 3D position of hundreds of points along that laser line are calculated, forming a profile of the target. By mechanically rotating the sensor head, a series of adjacent profiles are captured. The sequence of profiles forms a 3D point cloud of the target surface. Laser light emitted from the head of the sensor remains in a narrow band compared to a sonar beam which spreads out as it propagates. The energy footprint of a laser beam is therefore far smaller than that of a sonar beam, permitting a much higher measurement resolution.

Comparing Laser and Sonar Systems

Underwater laser scanners provide several clear advantages over sonar systems at relatively short ranges. The measurement resolution is multiple orders of magnitude higher, enabling very dense point clouds. Measurements made from dense laser point clouds will in general be much more accurate than those taken from relatively sparse sonar point clouds. Additionally, laser systems are not affected by confined spaces prone to acoustic echoes. The ideal application for an underwater laser scanner involves short-range, high-detail measurements of specific locations on an asset. Such applications include damage assessment, archaeological documentation, and as-built documentation including generating 3D CAD models.

	Laser Scanner	Sonar
Range	0-5m	>1m
Resolution	<1mm	~5cm

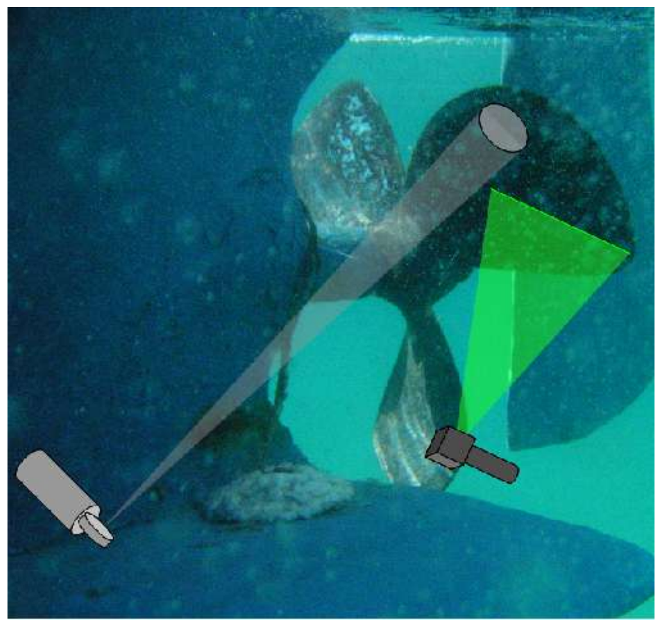

Figure 3: Hundreds of laser measurements are captured along the laser line. A single sonar measurement is captured over the entire sonar footprint.

Water clarity has a more significant impact on laser scanners than on sonar systems. Silt and turbidity can reduce the range of laser scanners underwater. Using the ULS-100, reliable measurements can still be taken in moderately silty environments because it employs robust silt filtering techniques. Extremely silty conditions, however, can blind laser scanners just as they blind video; if you can't see it, you can't scan it.

Results

To demonstrate the difference between the capability of sonar and laser for measuring underwater, a cinder block wall was constructed with target features including missing blocks and offset blocks. The wall was scanned with both the 2G Robotics ULS-100 underwater laser scanner and a mechanically scanning 3D sonar using a 2.25Mhz head with an average angular point spacing of one degree. The point cloud data for the two methods has been overlaid, with laser scanner data in red and black, and sonar data in green.

Figure 4: View of 3D Laser Data Point Cloud Aligned With 3D Sonar Point Cloud

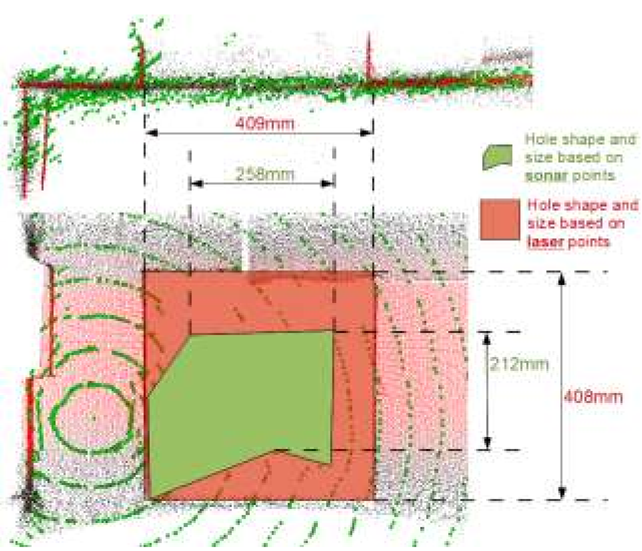

Figure 5: Top and Front View of hole in the wall indicating indicating the error potential with sonar measurements compared to laser data

The scans generally align well, indicating that both systems are capable of accurately assessing an asset's large-scale structure. However, there is significantly greater variability in the sonar measurements, and the measurement resolution is much lower, as shown in Figure 4. The laser system also resolves edges much more precisely than sonar. As Figure 5 illustrates, the hole in the wall is resolved with very good detail using the laser scanner. While it is possible to identify the presence and general location of the hole in the sonar data, it does not provide a precise understanding of the hole's edges and an accurate position and size for the hole cannot be determined. This inaccuracy is due to the size of the sonar system's footprint, as shown in Figure 6.

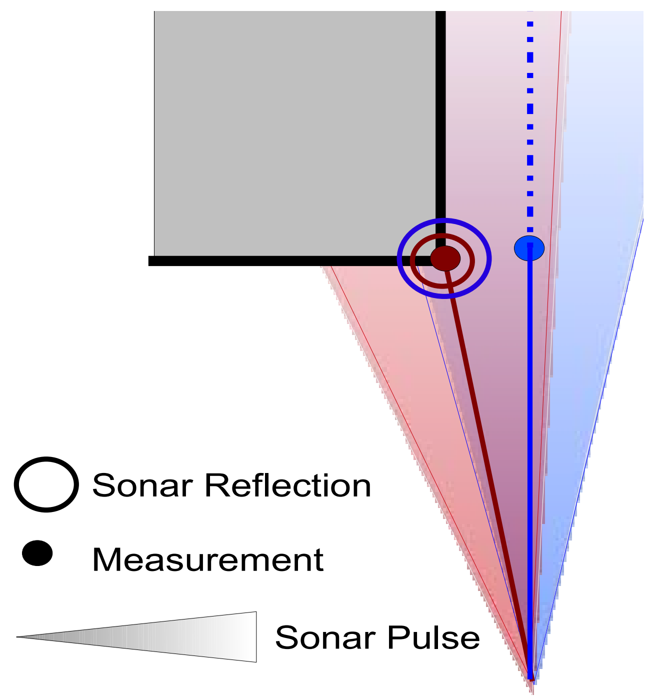

Figure 6: Two sonar pulses may have overlapping footprints, leading to incorrect measurements.
The red pulse is centred on the corner, and correctly resolves it.
The blue pulse is aimed at the hole, but due to the size of the footprint it also detects a return from the corner point. Because returns are assumed to come from the beam centre, the measurement is incorrect.

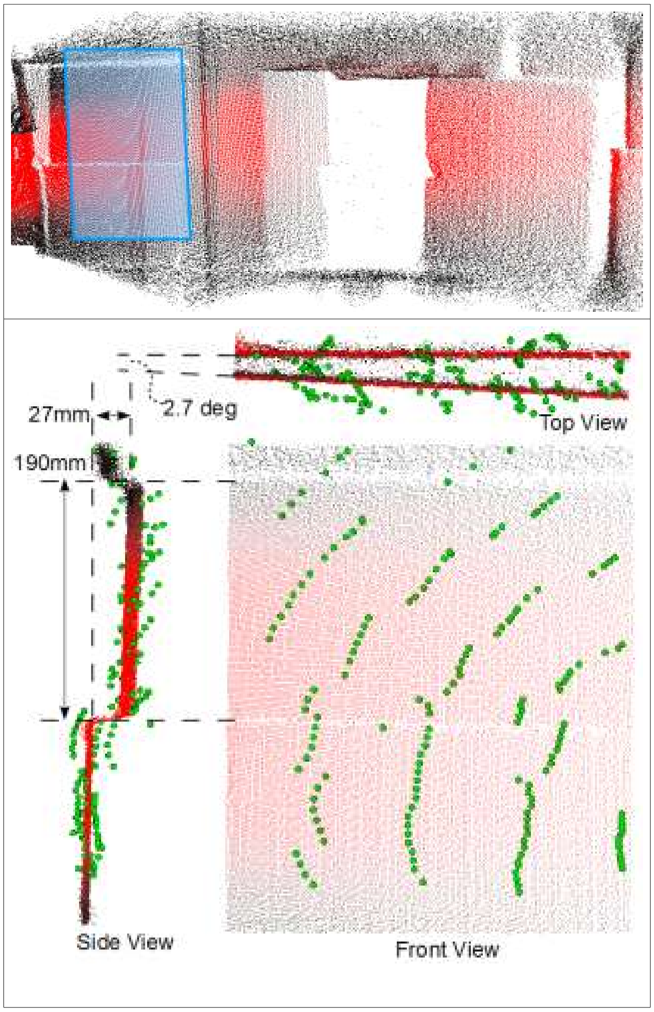

Figure 7: Measurements of the offset between two stacked cinder blocks demonstrate the variability of sonar data relative to laser data, and the much greater point density provided by laser systems.

The increased resolution and accuracy of laser measurements is important when considering smaller features. The offset between two cinder blocks, shown in Figure 7, is easily quantified by the laser scanner data while it is difficult to detect with the sonar data and would be challenging to quantify. A chip in the corner of a block, shown in Figure 8, does not appear at all in the sonar data. By surfacing the laser scanner data a clear understanding of this small but potentially important feature can be achieved.

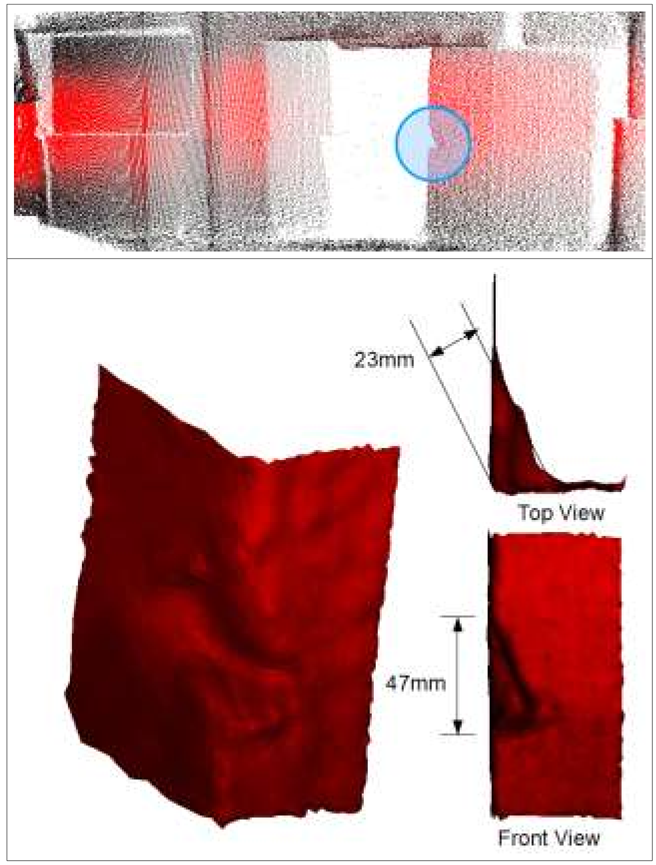

Figure 8: Surface visualization of a small chip in the corner of a cinder block. The size and shape is accurately modelled by the ULS-100.

Conclusions

Sonar and laser technologies have complimentary features. Long-range sonar scans can be used to assess the general structure of an asset, where high levels of detail are not required. Sonar can accomplish this quickly and at low cost, where laser scans of a large area can be time-consuming and more expensive. Once areas of interest have been identified, however, it is critical for engineers to fully understand the status of these locations. High-resolution laser scans of critical areas can provide the information necessary to ensure safe continued operation of these assets while minimizing unnecessary maintenance expenses. If maintenance is necessary, laser scanner data provides a more complete understanding of repair requirements, reducing risk and lowering the cost of deployment.

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