Feature Detection and Classification with Airborne Lidar
- Practical Experience

By

Geraint R. West
W. Jeff Lillycrop

Joint Airborne Lidar Bathymetry Center of Technical Expertise, Mobile, AL 36602[1]

Abstract

The measurement accuracy of airborne lidar is widely accepted as being at least comparable with conventional acoustic survey methods. However considerable debate has occurred over how effective it is at detecting and classifying bottom features and hazards. Modeling studies have suggested theoretical limits of feature detection, however practical experience has frequently suggested that these models are unduly pessimistic in their results. Partly as a result of this, the efficacy of lidar as an accepted survey tool has often been compromised, resulting in difficulty with establishing a universally accepted philosophy for its use. This paper examines practical examples of bottom feature detection and classification using the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system. These results suggest that poor perception by potential users, rather than technological limitations have often been the limiting factor on applications of lidar surveys.

Introduction

Airborne Lidar hydrography has become an accepted technique for surveying coastal waters from the air using a scanning laser. Although the depth measurement accuracy of current systems has been proven to meet or exceed International Hydrographic Organisation (IHO) standards (Riley 1995), it's acceptance as a fully functional survey tool requires a minimum target and feature detection capability. While conceptually a lidar system is similar to a multibeam echsounder (MBES), the individual laser shots display many of the drawbacks associated with wide-beam single-beam echosounders (SBES). However, close-sounding by SBES has for many years been one of the few accepted methods for establishing least depths over obstructions and the measurement density (or 'shot' density) of lidar is usually considerably better than that of a SBES. Practical experience from the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system supports this and demonstrates that lidar surveying is commonly capable of detecting small features and targets.

Lidar Principles

All Lidar systems operate on the principle that water depth may be calculated from the time difference between laser returns reflected from the sea surface and seabed. Commonly, an infrared channel (1064 nm) is used for surface detection, while bottom detection is from a blue-

---

[1] The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) was established in May 1998 by the signing of a Memorandum of Agreement between the US Army Corps of Engineer South Atlantic Division, the Waterways Experiment Station and the Commander Naval Meteorology and Oceanography Command.

green channel (532 nm). The basic geometry of the SHOALS laser is shown in *Figure 1*. Although source beam divergence is of the order of 12 mrad, producing a spot on the sea-surface of about 1.5m diameter, the many spreading and scattering effects mean that 90% of the energy is contained within a footprint of diameter approximately equal to the depth. However, much of this energy is returned with a significant time lag and is insignificant for measurement purposes. The consequence is that a footprint with a diameter of ½ the water depth (containing 50%) of the energy is normally regarded as the "effective' footprint of an ALB system. It is important though to realize that illumination of the bottom does not imply detection of small targets within the footprint and for this to occur, the ratio of illuminated target area to illuminated bottom area has to be sufficiently high to enable both automatic and human recognition. To understand the reasons for this it is necessary to briefly discuss how bottom detections are made.

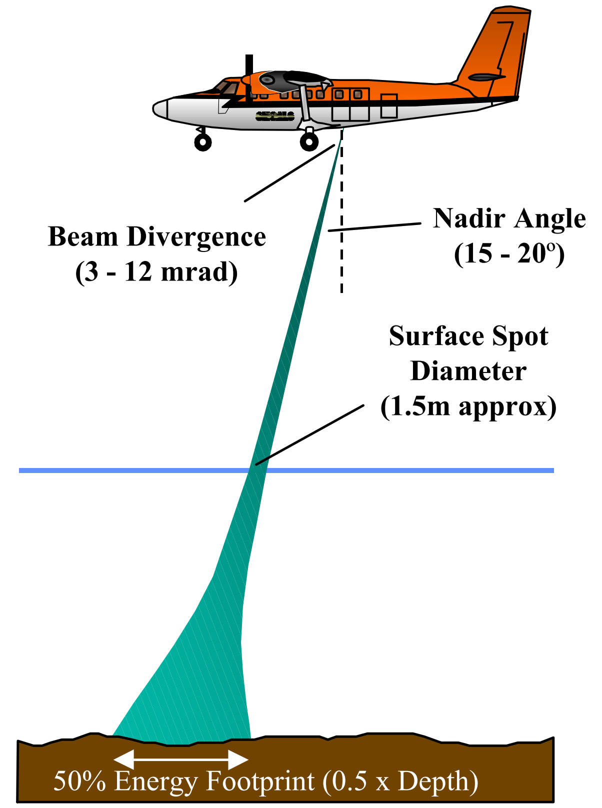

Figure 1 Laser Geometry

Although surface detection is usually made with the infrared channel, the blue-green channel will also detect the surface. Because of this the generic ALB waveform is of the type shown in *Figure 2*, with two distinct returns from the air/sea interface and the bottom. The asymmetry of the bottom return is a consequence of the large footprint, but as stated above, the "tail" is largely from outside the "50% diameter" footprint. Since the detection is measured on the leading "up" ramp of the waveform, it becomes clear why this scattered energy is irrelevant to the depth calculation.

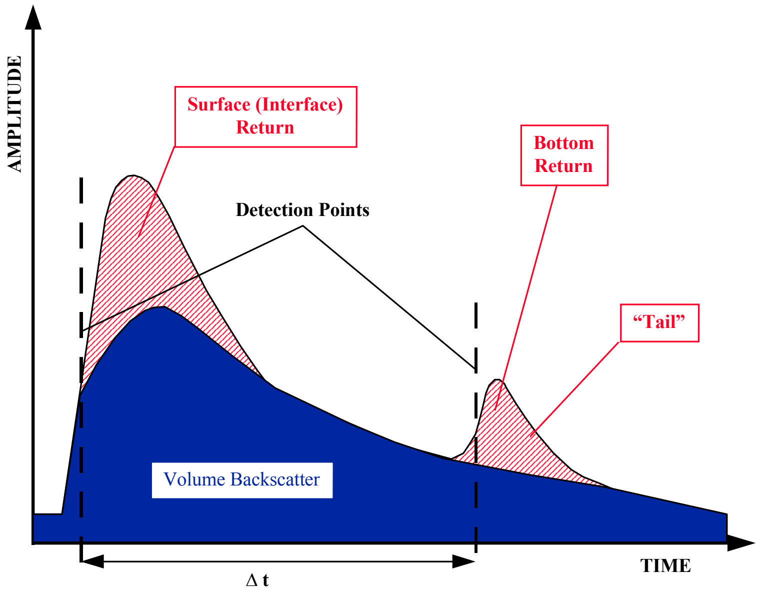

Figure 2 Generic Lidar Waveform

Figure 3 illustrates a typical shallow water waveform. The bottom is saturated on the deep channel, clearly illustrating why the use of two channels is preferred in the SHOALS system. In *Figure 4*, a deep return is shown; not only does this fall beyond the maximum depth of the shallow channel, but it has a low amplitude waveform resulting from considerable spreading of energy results in a large "footprint" that may get lost in noise.

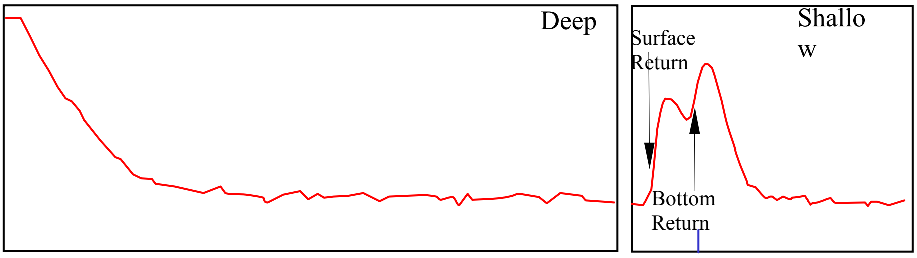

Figure 3 Shallow Water Waveform

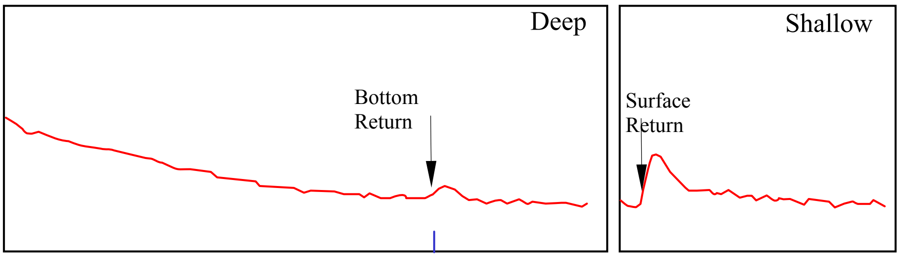

Figure 4 Deep Water Waveform

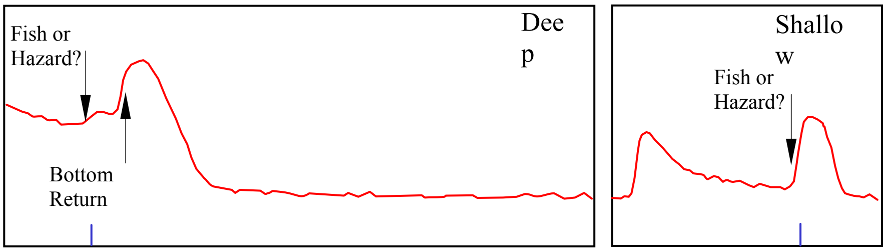

Figure 5 Waveform Showing Return Close to Seabed

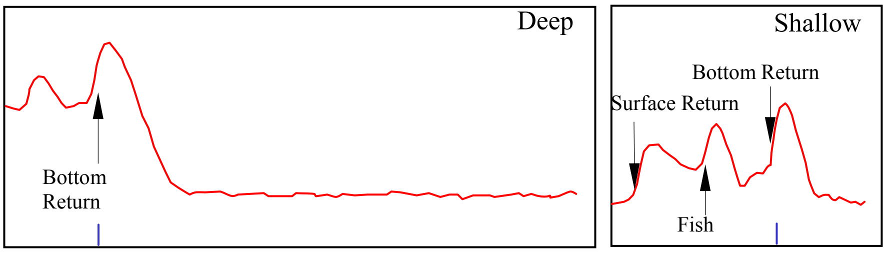

Figure 6 Waveform Showing Mid-water Column Return

Although the examples above describe the majority of cases, it is the determination of target detection capabilities that is fundamental to the characterization of Lidar as a hydrographic survey tool. The distinction between bottom illumination and confident target detection is therefore important to understand. *Figure 5* illustrates the case where there is evidence of a return above the bottom (deep channel), however the shallow channel shows this to be a distinct and separate return, so the likelihood is that this is fish. In *Figure 6*, both the deep and shallow channels show a separate return in mid water column, clearly indicating fish or other suspended material. These cases are just two examples of the problems posed in distinguishing apparent anomalies with real bottom hazards; the technology has changed, but the role of the hydrographer as an interpreter of the data has not. The situation becomes even more difficult in deep water, where small objects will illuminated by a decreasing proportion of the total incident energy so they become masked by the "up" ramp of the bottom return.

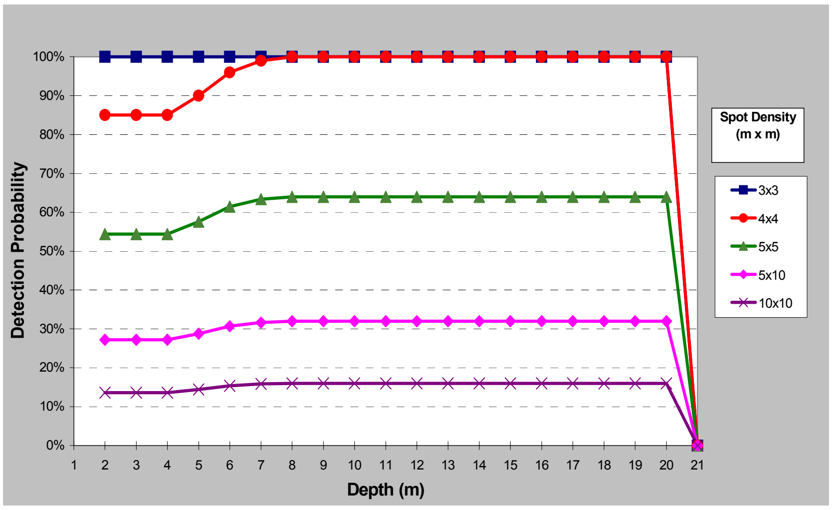

Figure 7 Probability of Detection of a 2m Cube by Different Spot Densities (After Guenther 1996)

Hazard Detection

So far only the single sounding (often known as a "shot" has been considered and it should by this point be clear that such a situation falls short of the requirements of a hydrographic system, both in coverage and object detection. Current Lidar systems employ a mechanical scanning mirror to achieve a swath, which when combined with the PRF of the laser produce a grid pattern of spots. Equally, the need for drawing a clear distinction between 100% bottom illumination and hazard detection confidence should also be recognized. Because of the need to illuminate a target with sufficient proportion of the laser footprint to result in a detection, denser spacing of shots will result in higher chances of detection.

This "sounding" spacing is generally referred to as spot density and considerable debate has occurred over recent years as to optimum spot density required for hydrographic purposes. Guenther et al (1996) highlighted this issue in a study from which *Figure 7* is developed. This is a stark illustration of the relative effectiveness of different spot densities and underlies one his conclusions, that, "significant gains can be obtained in many cases by decreasing average linear sounding spacing to 3 m." It was further concluded, "objects less than 1 m high are not frequently detectable. Consequently the need to define the envelope of ALB capabilities is an important step if it is to replace traditional acoustic systems in legitimate circumstances. It is in this area that the most significant work in proving the efficacy of laser hydrography can be done and while Guenther's work has been a leap ahead in the characterization of lidar for hydrography, the process of fully characterizing ALB performance is only in its infancy. In parallel with this, we are also challenged to fully define the capabilities of our older technologies and, moreover, to be honest whether they actually achieve the capabilities we have so often only assumed.

SHOALS

Probably the most versatile Lidar survey system in use anywhere in the world today, SHOALS has recently undergone a major upgrade to enable it to operate from either fixed wing aircraft or helicopter. The system was installed in a Twin Otter during the Fall of 1998 and has since completed projects in New Zealand, Hawaii and the Bahamas in addition to the Continental USA. SHOALS incorporates a 400Hz laser scanning a swath of up to 220m with a selectable spot density of 3 – 15m. Depending on selected scan width and spot density the system can be flown at speeds of up to 120kts. A single operator can operate the airborne system, but due to the extended duration of flights, it is usual to fly with 2 operators. Data is recorded onto Exabyte 8mm dual tape drives, which are also used for loading survey flight planning data. After landing the data is processed by specialized post-flight depth extraction procedures that calculate depths, positions, and corrects for tides and waves. Automation is maximized in this part of the software so that the amount of human intervention is reduced, producing a time ratio of 1:1 with data collection. The output from the automated processor can then be accessed via a manual processor interface, which is the primary method of editing and quality controlling data. The final post-processing product is an ASCII x,y,z file which can be imported into any standard CAD package for mapping.

Practical Examples

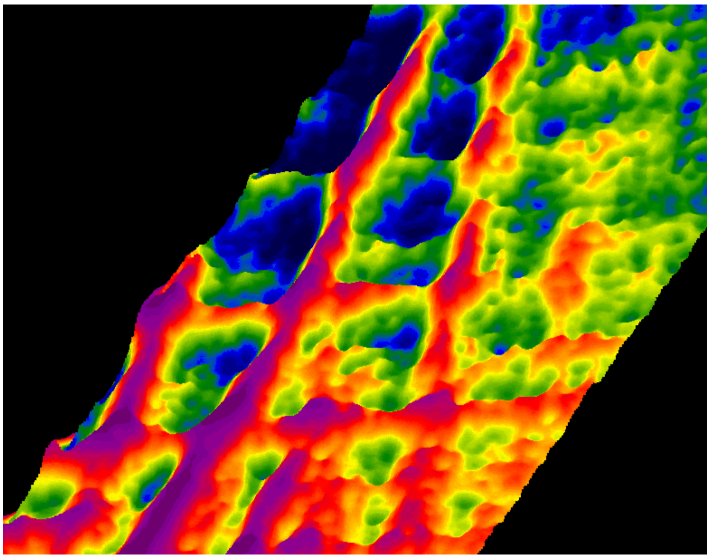

Figure 8 Intersecting Sandwave Fields

SHOALS normally employs a 4m x 4m shot density; this means that it is able to collect dense data sets in shallow waters that would take conventional acoustic systems many times longer to collect. *Figure 8* is a good example of the detail that is obtainable in shallow water. This example shows two sets of intersecting sandwaves that were detected in general depths of 6.5m during a recent survey in the Bahamas. The data comprises an area of approximately 1000 x 2000 and was collected during different flightlines on different days. The vertical scale has been exaggerated to highlight this structure, but the highest of the sandwaves is only 1.1m high while the width varies from 15 – 50 m.

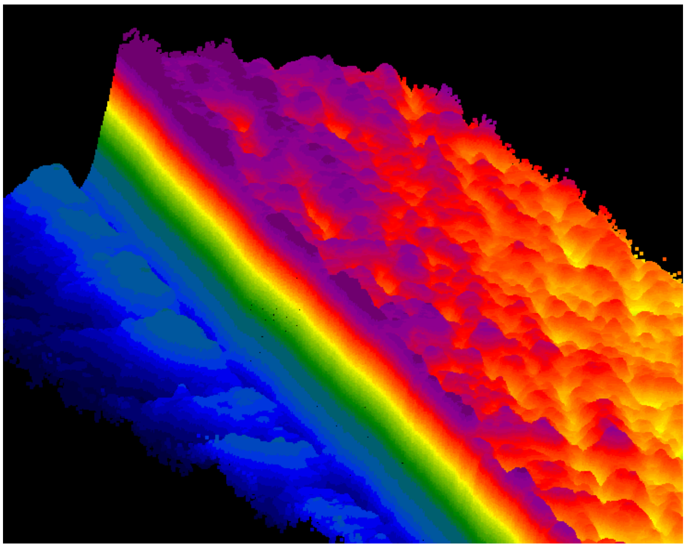

Figure 9 Major Sandwave

Figure 9 shows an area in the same locality. This ‘cliff’ which stretches for over 6 km is however only 2.1m high and is about 40 m from crest to trough. Again, though, the general water depths are all less than 8 m, and lidar is probably the only tool that can track a feature of this size in such shoal water.


Figure 10 SHOALS Down-look Video of 'Blue Hole'

Taking this further, it has also been possible to use SHOALS to delineate smaller area features, including several 'Blue Holes'. The data shown in *Figure 11* is from one such feature and shows the 'Blue Hole' to be about 40 m in diameter (crest to crest), with general surrounding water depths of about 3 m. The aircraft was flying from bottom-left to top-right, so the data can be directly compared with the in-flight down-look video record, which is collected simultaneously with all SHOALS surveys. In the video, the aircraft is flying from bottom to top, and the lighter right-hand side of the hole's crest is easily correlated with the yellows on the nearest side of the crest in *Figure 11*. Also visible in *Figure 10* are the streaks that run down-slope into the deeper water at the top-right of *Figure 11*.

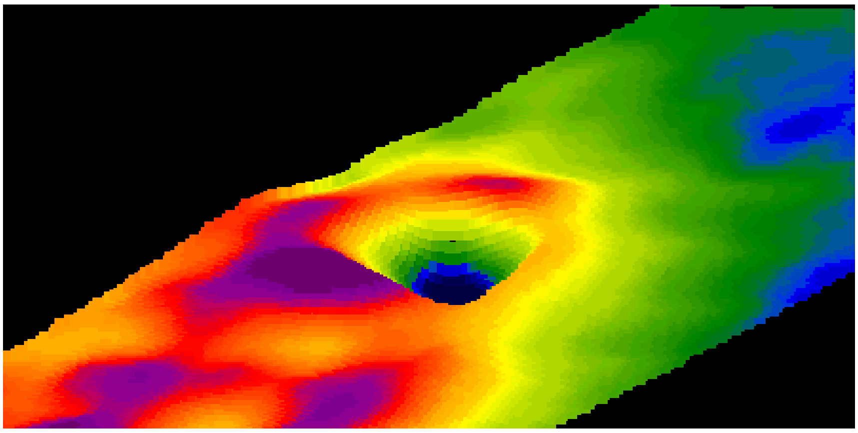
Figure 11 'Blue Hole'

Of course, these features are large in horizontal extent and do little to prove the capability of lidar to detect small discreet targets such as rock pinnacles or wrecks. The next example remedies this and shows a wreck detected by SHOALS during a survey in Mexico. *Figure 12* clearly shows the vessel on the seabed and about 30m in length, while *Figure 13* shows the wreck in 3D view. What is significant about this wreck is that the highest point of was located at a depth of 6.2 m in general depths of 9 m, while much of the body of the wreck had

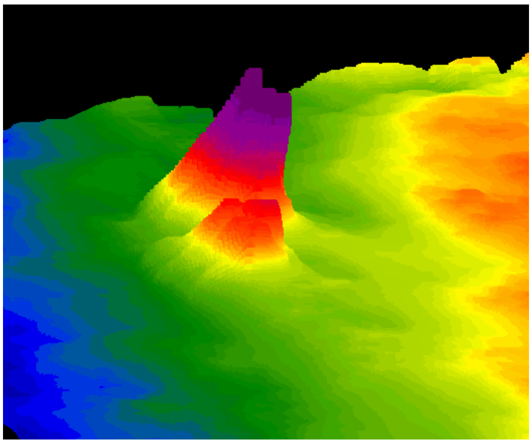
Figure 13 Wreck

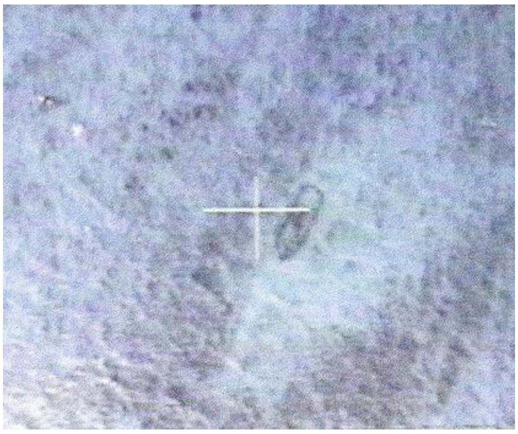
Figure12 SHOALS Downlook Video of Wreck

sunken into the sand and protruded less than a meter above the surrounding seabed. It should be clear from this example that lidar has a proven capability to detect even small wrecks.

The final example is taken from one of the most challenging environments that SHOALS has ever worked in. The rocky coasts of New Zealand's Sub-Antarctic Islands are characterized by extreme surf and spray conditions as well as bottom topography which is dominated by isolated pinnacles. *Figure 14* shows typical coastal area composed of both drying and submerged rocks. The drying and breaking rocks are obvious in the photograph, but a submerged pinnacle lies to the bottom-right of the 'doughnut' shaped rock. This particular pinnacle rose from a depth of 15 m to within 7 m of the surface and had a base cross-section diameter of less than 10 m. It should be obvious that an area such as this is a particular challenge to survey by conventional acoustic means and that lidar becomes a significant tool when it can release surface vessels from surveying such hazardous areas.

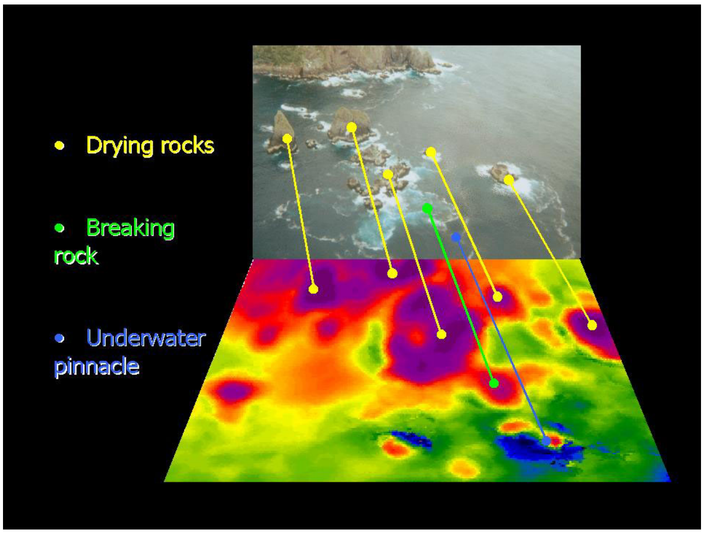

Figure 14 Shallow-water Rock Complex, New Zealand

Conclusion

Much work is still to be done to fully characterize lidar for small feature surveying. However the practical examples above show that lidar is capable of revealing complex bottom structures as well as small (and often hazardous) features in shallow water. While lidar will never be able to challenge high-frequency sidescan sonar as the tool of choice for object detection surveys in shallow water, it is evidently more capable in this field than many would give it credit for. Increased appreciation of this fact will surely mean that more users can benefit from this flexible and highly capable technology.

References

Guenther, G.C., T..J. Eisler, J.L. Riley, and S.W. Perez, 1996. "Obstruction detection and data decimation for airborne laser hydrography," Proc. 1996 Canadian Hydro. Conf., June 3-5, Halifax, N.S.

International Hydrographic Bureau. "Standards for Hydrographic Surveys", International Hydrographic Organisation Spec. Pub. No. 44.

Pope, R.W., B.A. Reed, G.R. West, and W.J. Lillycrop, 1997. "Use of an airborne laser depth sounding system in a complex shallow-water environment", Proc. Hydrographic Symposium XVth Int'l Hydro Conference., 21 -22 Apr. 1997, Monaco.

Riley, J.L., 1995. "Evaluating SHOALS bathymetry using NOAA hydrographic survey data," Proc. 24th Joint Mtg. of UJNR Sea-Bottom Surveys Panel, Nov. 13-17, 1995, Tokyo, Japan.

West, G.R., T. Graham, K. Smith, J. Spittal, 1999. "Improving the efficiency, safety and economy of the New Zealand National Charting Programme through the integrated use of Lidar in a multi-sensor surveys", Proc. 1999 U.S. Hydrographic Conference., Apr. 26 – 29, Mobile, Alabama.