SIGNIFICANCE OF LASER AIRBORNE TECHNIQUE FOR SHALLOW BATHYMETRY CHARTING

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1.0 INTRODUCTION

Airborne laser (or lidar) bathymetry (ALB) is a technique for measuring the depths of relatively shallow, coastal waters from the air using a scanning, pulsed laser beam. Lidar technology utilizes the reflective and transmissive properties of water and the sea floor to enable measurement of water using a laser. When a light beam hits a column of water, part of the energy is reflected off the surface and the rest, unless absorbed by particles in the water, is transmitted through the column.

As the light travels through the water column and reflects off the seafloor, scattering, absorption, and refraction all combine to limit the strength of the bottom return, and therefore the system's maximum extinction depth. This depth is a function of water clarity, and is generally about three times the secchi depth (The Secchi depth is an old and intuitive water clarity measure which is the depth at which a standard black and white disc is no longer visible to human eye.)

It is also known as airborne lidar hydrography (ALH) when used primarily for nautical charting.

2.0 HISTORY OF AIRBORNE LASER BATHYMETRY

The Concept of Airborne Laser Bathymetry evolved from the efforts made in mid 1960 s for using laser in finding submarine. The seminal paper confirming the ability to use laser for near shore bathymetry was written by Hickman and Hogg. The First generation airborne lidar (Light detection and ranging) system was developed and tested successfully in 1970 s by NASA in US, Canada and Australia. The second-generation systems laid stress on the design and goals and NOAA and NASA carried out much work. The system developed was called Airborne Oceanographic Lidar (AOL).

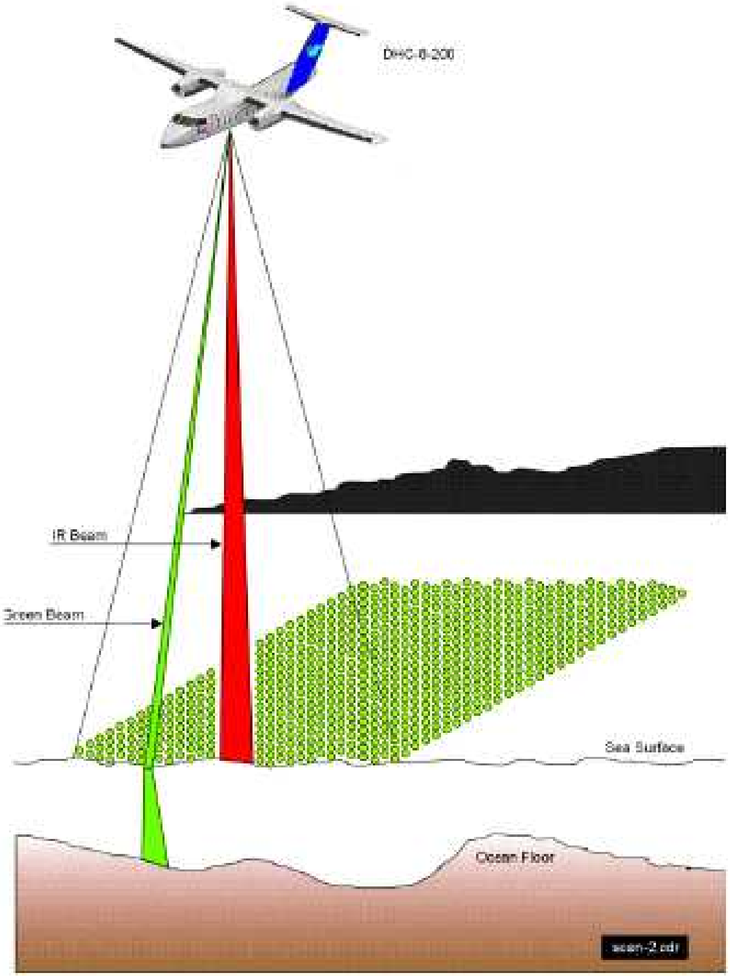
In the 1980's, the Larsen-500 was developed in Canada, and, based on surveys performed in the Northwest Territories; it became the world's first operational ALH system. Testing of the Australian WRELADS II was completed, and construction was begun on the operational version called LADS for the Royal Australian Navy. LAD is flown in a dedicated Fokker F-27 fixed-wing aircraft. SHOALS of US originally operated from either of a pair of NOAA Bell 212 helicopters, while two Hawkeye systems were borne in several different types of helicopters. The Canadian Larsen-500 system continued to perform in several fixed-wing aircraft (71). Late in the decade, the LADS II system, with a much higher pulse repetition rate than its predecessor, became operational in a Dash 8 aircraft. SHOALS added the capability of using kinematics GPS; this permits topographic mapping over land to be conducted in conjunction with bathymetric missions. The pulse repetition rate of SHOALS was doubled , and the system was transitioned from the helicopters to a Twin Otter fixed-wing aircraft. Several additional nations, such as India and Japan, are expressing interest in purchasing systems, and a number of others, such as Mexico, New Zealand, Norway, Indonesia, and the United Arab Emirates, have contracted surveys with the above systems.

3.0 RECENT DEVELOPMENTS

In 1998 new generation systems were commissioned for commercial survey, providing more efficient, faster and more accurate survey at greater depths. These new systems are now deployed worldwide in a wide range of applications including nautical charting and in support of oil and gas exploration and production, EEZ baseline delimitation, oceanography, fisheries management, coral reef and marine resource management.

Accurate, high-density laser airborne bathymetric data can be modelled for many hydrographic and oceanographic applications. Australia s Laser Airborne Depth Sounder (LADS MkII) is used to demonstrate the updated capability and efficiency of the airborne laser bathymetry

Fig 1. LADS Survey operation



Caption: LADS MkII captures data at up to 65 sqkm/hour using visible blue-green laser pulsed in a 240 metre swath at 900 pulses per second.

4.0 CONCEPT OF LIDAR

Airborne laser bathymetry is a comparatively young and growing discipline, which depends on state-of-the-art engineering in areas of lasers, optics, and electronics. The general technique of ALB involves the use of a pulsed laser transmitter with both green and infrared (IR) output beams. Green is selected for sea bottom detection because that is the wavelength, which penetrates typical coastal waters with the least attenuation. Infrared light penetrates very little and can be used for detection of the sea surface location. Depending on system design, the IR beam may be nearly collimated and scanned collinearly with the green beam, or it may be broader and constrained at nadir. Red energy generated in the water from green-excited Raman backscatter immediately beneath the air/water interface may also be used as a surface return when its arrival time is properly corrected to the interface. The transmitted laser pulses are partially reflected from the water surface and from the sea bottom back to the airborne receiver. In effect, distances to the sea surface and bottom can be calculated by measuring the times of flight of the pulses to those locations and knowing the speed of light in air and water. Water depths are determined from the resulting time differences and corrected for known errors such as electronic delays. A conceptual green lidar return waveform, as seen in an airborne receiver, is shown in Fig. 2.

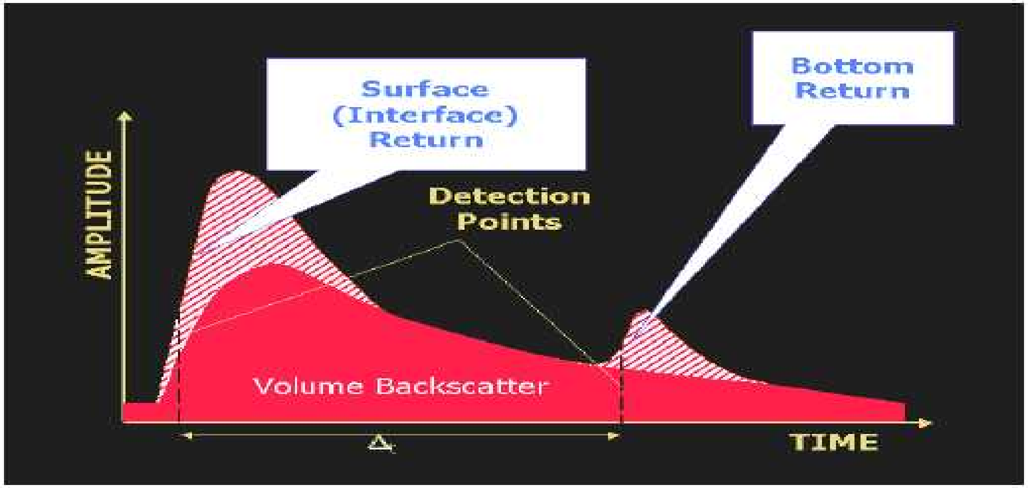


Figure 2: Schematic green lidar waveform showing the three principle signal components.

The green and IR beams are purposely expanded to a diametre of at least several metres at the water surface in order to achieve eye safe operation. More beam spreading is caused by the optical effects of waves on refraction angles at the water surface. In all but very shallow water, however, most of the beam spreading occurs in the water column. Although laser beams are commonly envisioned as being highly collimated with a small cross section (as they are in space or over short distances in air), this is not the case in water. Here, scattering causes even the narrowest beam to expand into a cone whose interior angle and cross section increase significantly with depth. Related propagation-induced depth measurement biases must be corrected. The resulting net expansion in irradiated bottom area is beneficial to the detection probability for significant bottom features but as with broad sonar beams, can be detrimental to depth accuracy when high relief features are present. The receiver consists of a telescope, various optical filters and field-of-view controls, light detectors, amplifiers, analog surface detection logic, and analog-to-digital converters (a digitizer). The receiver, system control logic, and tape storage are all operated under computer command. Because of the complexity of the environment and of the interactions of the lidar beam with the environment, it has not been possible to calculate all depths with high accuracy and reliability in real time. Approximate depths are calculated in the air for quality control, but precise depths, involving more-detailed calculations and a limited amount of manual intervention for difficult cases, are determined via post-flight processing of stored waveforms. Typical aircraft altitudes are in the 200-500 meter range. An optical scanner provides coverage of a broad swath under the aircraft track. Scan patterns vary from system to system; both semi-circular and rectangular are in use. The maximum scanner nadir angles in use are 15-20 degrees; this leads to surveyed swaths with widths roughly equal to one half of the aircraft altitude. Larger angles would cause unacceptably large pulse timing errors in both surface and bottom returns due to the more extreme geometry. Coverage is dense; surveys of most systems are done with soundings spaced on a 4 or 5 metre grid.

This density is achieved with laser pulse-repetition rates from 400 to 1000 pulses per second. If a programmable scanner is employed, higher sounding densities can be achieved for special purposes, for a given altitude and pulse-repetition rate, by reducing the swath width. Conservative gross coverage rates, for the case of a 100-kt speed and a 110-m swath width, for example, are on the order of 5000 m2/sec. The net rate achieved depends on factors such as the swath overlap and the fraction of time spent in turns. In this example, for a 6-hour mission (a typical day's work) with a 65% on-line fraction, about 70 km2 would be surveyed. With a wider swath and/or a faster aircraft, even higher coverage rates could be achieved at this sounding density. The limiting factor is the laser pulse-repetition rate.

Although ALB is most frequently used alone to good advantage, it is generally complementary with surface-borne sonar bathymetry techniques. Lidar systems, with swath widths nearly independent of depth, are very efficient in relatively shallow waters. Multibeam sonar systems, whose swath widths decrease with decreasing depths, are more efficient in deeper waters. Because of depth, water clarity, safety, or weather limitations, a survey area may break down naturally into regions best served by airborne and water-borne approaches (10). ALH can also be used safely for survey planning, prior to a sonar survey, in order to delineate dangerous areas and features that might imperil the survey vessels (82). Airborne lidar is not a replacement for sonar; it is a new tool that can be utilized with great cost and coverage benefit under the proper circumstances.

5.0 PERFORMANCE CHARACTERISTICS

The New Generation LADS MKII was brought into commercial service in September 1998. LADS MkII incorporates improved laser, computer and navigation technology in a faster aircraft platform, enabling the system to collect higher density data at deeper depths and at higher productivity. Some of the features of LADS MkII s performance characteristics are as follows: -

Sounding Rate	900 Hz (3.24 million soundings/hour)
Area coverage	19 sq nm/hour (64 square kilometres/hour)
Sounding density	5m x 5m (2m x 2m, 3m x 3m, 4m x 4m capability)
Swath width	240m
Depth range	0.5m to 70m
Depth accuracy	S44 IHO Standard for Hydrographic Surveys Special Publication of 4th Edition 1998, Order 1
Output	Fair sheet plots and digital data in ASCII format

Summary of Minimum IHO Standards for Hydrographic Surveys

(IHO Special Publication No. 44 1998).

ORDER	Special	1	2	3
Examples of Typical Areas	Harbours, berthing areas, and associated critical channels with minimum underkeel clearances	Harbours, harbour channels, recommended tracks and some coastal areas with depths up to 100m	Areas not described in Special Order and Order 1, or areas up to 200m water depth	Offshore areas not described in previous categories
Horizontal Accuracy(95 percent Confidence Level)	2m	5m+5 percent of depth	20m+5 percent of depth	150m+5 percent of depth

6.0 LIMITATIONS

The Most Significant limitation of ALB is water clarity, which limits the maximum survey able depth. In general LADS can measure depths two to three times the optical depth as measured by a Secchi disk. Thus:

a) In pristine waters (e.g. Coral Sea, Red Sea) LADS surveys to over 70 metres;

b) In clear coastal areas (e.g. Great Barrier Reef, Arabian Gulf, Timor Sea, northern Norway) from 40 to 50 metres;

c) In less clear coastal areas (e.g. South Australia, New Zealand, Alaska) from 30 to 35 metres;

d) In moderately turbid water (e.g. Torres Strait in dry season, southern Norway) from 15 to 25 metres; and

e) In very turbid water (e.g. Torres Strait in wet season) from 0 to 15 metres.

f) Sea state: LADS efficiently surveys in sea states up to 3 or 4. At higher sea states the frequency of white caps (which later require editing during data processing) reduces efficiency of survey data validation.

The other limitation is of small object detection, which arises due to, difficult in detection of laser signal from small object in comparison of much stronger and immediate bottom signal. The detection for small object can be increased by greatly increasing the survey density and the data should be compared with high frequency sonar data.

7.0 APPLICATION AREAS

Typical applications for Navigational Charting include:

1. Bathymetric surveys for navigation channels, large offshore areas, ports and harbors, shore protection projects such as jetties and breakwaters, coral reefs, beaches, shorelines, and dredge disposal sites.
2. Delimitation and survey of territorial seas and EEZs;
3. Planning and management of marine resource utilization
4. Exploration and development of offshore hydrocarbon and mineral deposits;
5. Management of India s marine, coastal and reef zones.
6. Airborne laser mapping (or LIDAR - Light Detection And Ranging) is a fast and reliable method of obtaining3-dimensional data for the creation of a digital terrain model (DTM). It is also capable of producing a DTM to an accuracy of ±15 cm, the system is useful for applications where a relatively high degree of accuracy is necessary, but over a narrow swath. In addition, a laser DTM can be produced in a shorter time frame than a similar product using conventional photogrammetric techniques.

8.0 COST BENEFIT RATIO

Experience with SHOALS has shown that, for appropriate and properly planned projects, the cost of ALB is from one-fifth to one-half that of waterborne techniques, depending on the logistical situation. Similar cost benefits have also been found in Sweden and Australia. Furthermore, ALB provides unique survey opportunities, capabilities, and products, in shallow water and across the land/water boundary, which would be worth having even if they cost more.

Figure 4 presents a graphic comparison of lidar and sonar operations in shallow water.

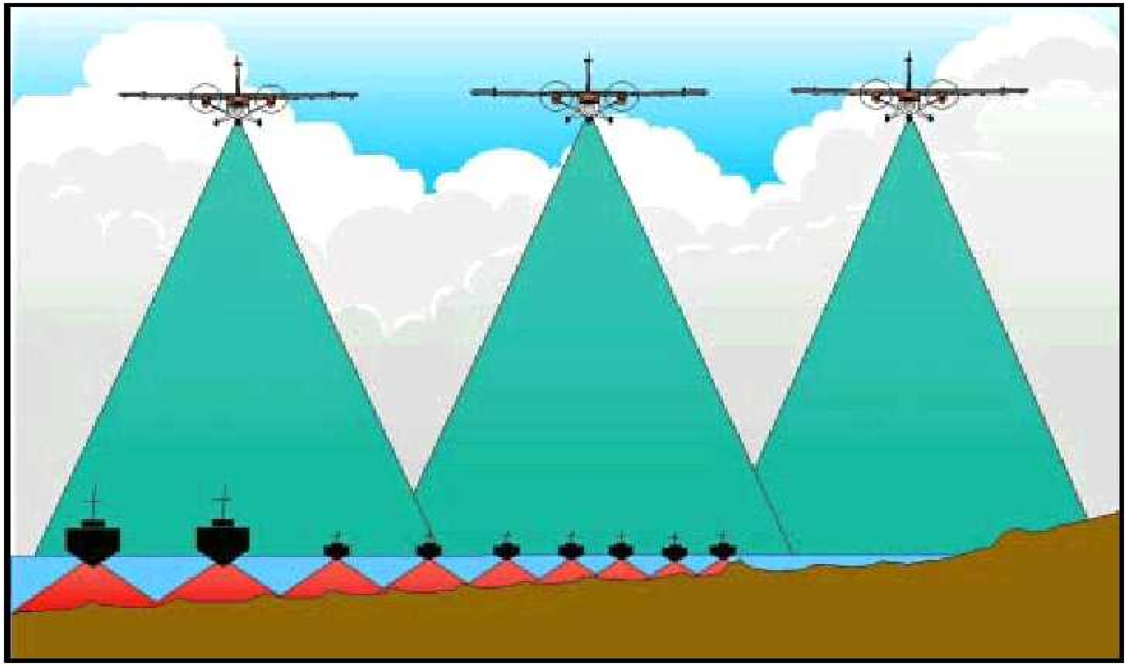


Figure 4. Depiction of lidar and multi-beam sonar operation in shallow water to emphasize lidar capabilities and efficiency.

Thus the primary reasons for pursuing this technology are that, for shallow areas, it provides:

1. The LADS has the ability to perform surveys quickly, in both large and small project areas, in a more cost-effective manner.
2. It has the capability to survey where it would be difficult, dangerous, or impossible to use water-borne techniques
3. It has the facility to simultaneously survey the sea bottom, the adjacent beach, and coastal engineering structures (both above and below the waterline
4. Its mobility to perform rapid assessments of seasonal change and storm damage.
5. It has the capacity to quickly complete surveys during favorable environmental windows in areas, which are unavailable to traditional techniques for long periods due to conditions such as ice cover etc.,

9.0 CONCLUSIONS

It can be concluded that Airborne Lidar bathymetry can be an accurate, capable and cost effective technique for shallow water bathymetric charting. ALB can survey safely in the areas where sonar cannot, including on land, but it is not a substitute for sonar. The vertical depth accuracy as desired by IHO for shallow water hydrography i.e. ±25c.m. (one sigma) could only be obtained after detailed understanding of the characteristics of the laser and optics, hardware, software and the physical interactions between the laser beam and environment. The efforts should be put to develop an accurate, capable, reliable and cost-effective lidar bathymetry system.

10.0 REFERENCES

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