Understanding LiDAR Bathymetry for Shallow Waters and Coastal Mapping

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SUMMARY

Airborne laser bathymetry offers the hydrographic community a very rapid and thorough wide area coverage solution for charting and data acquisition in shallow waters and along the coastal zone. Its non-impact technology provides the perfect solution for imaging delicate environments and for sensitive ecosystems. In particular, LiDAR bathymetry can survey, at IHO Order 1, those areas that are either denied to vessel based systems or where the risks are too great.

The paper looks at the results obtained from trials and commercial projects undertaken by Admiralty Coastal Surveys, a collaborative venture of the UK Hydrographic Office with Blom ASA and Airborne Hydrography AB.

In particular, the paper discusses the benefits and advantages, as well as the disadvantages, of LiDAR bathymetry acquisition and provides a brief review of the recent developments in data acquisition and processing.

During the accompanying presentation, the cost-benefits of the technology are compared and contrasted with conventional solutions for a range of end-user applications. Finally, because LiDAR can cover sea areas many times faster than conventional surveys, LiDAR project planning, efficient operational methods and complementary values with multibeam echosounder surveys is discussed.

In the presentation accompanying the lecture, the speaker will provide further illustrations and supporting economic models.

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1. INTRODUCTION

Bathymetric surveys using laser energy to penetrate the water column have, in the last ten years, developed to the point where the method provides a viable, cost-effective alternative to acoustic swath methods. Currently, there are three main commercial manufacturers of the technology: Optech (Canada), Tenix LADS Corporation (Australia) and Airborne Hydrography (Sweden).

Admiralty Coastal Surveys AB, a collaborative venture of the UK Hydrographic Office with Blom ASA and Airborne Hydrography AB, own and operate the Hawk Eye II Airborne Laser Bathymetry & Topography System (ALBTS) developed exclusively for the company by Airborne Hydrography AB. ALBTS uses light energy to penetrate seawater in much the same way as a multibeam echosounder, to produce a swath of bathymetry of the seabed. The constant swath width (usually half the flying altitude), aircraft platform, and rapid speed of advance, make ALBTS more efficient than conventional ship borne surveys in shallow and complex waters and among archipelagos and reefs.

The Hawk Eye system comprises a twin laser generator providing an effective depth sounding frequency of 3.6kHz and a (simultaneous) topographic laser operating at an effective 64kHz. A high-resolution digital camera is included to collect water colour information and to provide a continuous orthophoto record of each flight path. The Hawk Eye system is the most compact of the commercially available systems and has been designed to be portable for operations in a small to medium sized aircraft. The package includes ground equipment for mission planning and hydrographic / topographic data processing. An integrated differential GPS system hardwired into the Hawk Eye II provides high precision positioning of the water surface and seabed laser spot, and of objects in the water column in three dimensions. For high order surveys RTK DGPS, or carrier phase post-processing, is used.

The basic laser sounding principle is similar to acoustic methods. A pulse of laser light is transmitted from the ALBTS towards the water surface in a predefined pattern. The red laser light is reflected at the water surface whereas the green laser light penetrates into the water volume. The green laser light is reflected in the water volume and from the seabed. A portion of the reflected light is collected in the ALBTS receivers. The water depth is equal to the time elapsed between the two echo pulses, multiplied by the speed of light in water. Typical water depth penetration is in the range 20-40m but, in good conditions, depths as great as 70m are possible.

Hawk Eye II’s unique multi-pixel detection system uses four receiving pixels to split the bathymetry green laser spot into quadrants. This acts as a 4x multiplier on the pulse repetition frequency (PRF) giving a point spacing of 1.4m under normal survey operations. The topographic laser, which operates simultaneously, uses an 8 pixel detection system.

2. HAWK EYE II DEVELOPMENT AND EVALUATION

The sensor platform is 0.33m3 and weighs 87kg. The system requires only power and a GPS aerial feed from the host aircraft. Operation is via a high specification laptop computer, which also hosts the processing software.
The acceptance trials of the system comprised firstly of a series of static trials conducted in an underground submarine pen open to the waters of the Baltic. The objectives of the static tests were to determine:

- Horizontal discrimination
- Vertical discrimination
- System characteristics

The ALBTS system was mounted in a rigid frame set 20m above the water surface where the water depth was about 7 metres. The system was operated over several days to provide functional experience and determine the measurement characteristics. The standard deviation of the static measurements was of a very high order (<7mm) and the depths measured were consistent, meeting Admiralty Coastal Surveys / UKHO system acceptance criteria set at IHO Special Order. A cube detection test (part of the IHO SP44 criteria) determined that the system was capable of discriminating the edge of a cube as it was moved beneath the static laser.

A series of controlled dynamic tests employed a calibrated platform laid on the test chamber floor. The ALBTS was set to its scanning mode and the platform raised and lowered through the water column to simulate changing seabed topography; a small target on the chamber floor acted as a fixed reference. After these tests, the platform was raised towards the water surface to determine the limits of the ALBTS’s depth discrimination capability; 0.1m.

Having passed it controlled trials, the system was installed in an Air Commander aircraft for dynamic field trials. These trials were conducted over a period of many weeks in Lake Vattern, Sweden. All the initial results met the criteria set by the UK Hydrographic Office for compliance. The trials concluded with a series of cube detection tests, including unalerted detection, using 2m cubes set on the bottom in 18m of murky lake water.

Dynamic trials followed the static and controlled trials to prove the system’s capacity to meet and exceed the IHO Order 1 survey specification. IHO Special Order requirements in depths of ca. 10 metres were met. In a number of dynamic trials conducted in Norway, Sweden and the UK, The Hawk Eye II proved its capabilities for depth measurements to IHO Order 1 and for meeting the critical unalerted detection of 2m cube objects. The dynamic trails also allowed the engineers to refine the HMI, to fine-tune the detection and discrimination algorithms, and to make direct comparisons with surveys from multibeam and single beam

echosounders. In summary, after a year of extensive supervised trials, demonstrations and test surveys, and finally certification to IHO Order 1, the Hawk Eye II was commissioned for commercial projects.
In early 2006, a special survey was performed off the coast of Norway. The area selected by the Norwegian Hydrographic Office had been surveyed many times by single beam and multibeam echosounders and, to be on the safe side, another survey was made for Admiralty Coastal Surveys with a EM3003 multibeam echosounder. A detailed depth comparison between the data sets showed the ALBTS was, on average, 10-15cm shallower than multibeam but almost the same as the single beam sounder, and significantly more accurate than the multibeam spread of 0.40m obtained during the 2005 Plymouth Shallow Water Trials.

3. PROJECTS

Shallow rivers and their approaches offer a particular challenge to conventional survey methods. Equally challenging are complex areas of rocks, reefs and small islands in active sea areas and where there are high tidal ranges. Such areas are often environmentally sensitive, for example marine parks, where non-intrusive airborne survey methods have obvious advantages.

Whilst the economic value of the coastal zone is well understood, the potential value of inland waterways is possibly less well appreciated. In 2003 around 6% of the EU 25's freight transport was carried on rivers and canals. Even in UK, where the percentage of total freight moved on inland waterways is small, this still comes to a lift of 3.2 million tonnes annually. One of the valuable commodities moved via inland waterways is, of course, water, and knowledge of the volume capacity of canals and rivers is of significant economic value.
Since commissioning, Hawk Eye II has been used by Admiralty Coastal Surveys on many projects throughout Europe. As a proof of concept, ALBTS is undoubtedly superior to conventional solutions and, in many circumstances, offers the only safe and economic method of gathering bathymetric data.

The practical value of ALBTS surveying was demonstrated during a 60 km2 hydrographic survey in western France. Much of the area comprised of shallow waters littered with numerous shoals and reefs through which passed narrow navigational channels. A survey of the area by acoustic swath methods, would have taken 40 days (not including weather downtime). However, the breaking seas around the critical reefs and shoals, coupled with the high tidal range, would have posed unacceptable risks to a hydrographic survey launch. By ALBTS, the area was fully surveyed in less than two days.

Another example of shallow water survey in difficult environmental conditions were two sites in Northern Ireland. Each site was only 30km2 but, by encouraging cooperation between customers, an economically viable area of 60km2 resulted. One area was a UN designated Site of Special Scientific Interest (SSSI) in Strangford Lough, Northern Ireland, the other a research area in Red Bay. The survey was completed in a single day's flying.

As a final example of how ALBTS can operate safely in treacherous areas, the Longships Reef, off Land's End, was surveyed as part of a program of seafloor mapping. The results were phenomenal and represent the first complete data set that it has ever been possible to collect and the result speaks for itself.

4. ECONOMICS OF WIDE AREA ALBTS BATHYMETRY

The key to effective and cost efficient ALBTS surveying is planning. Aircraft move fast across the ground and their turn rates, while equally fast, can exceed the time on line. For example, a turn for a 100m swath width will take approximately two minutes. In the same time, the aircraft could cover some 9km of survey line, or approximately 2km2. The key, then, is to plan the survey to maximise the number of long lines (compounded if need be) and minimise the number of turns. Traditional ship survey planning tools, and similar techniques, are inappropriate for ALBTS surveys and, if used, will lead to significantly misleading results and bad judgments.

There is a common and widely circulated miscomprehension that airborne ALBTS surveys are expensive. The confusion arises over the day rate of an airborne ALBTS system compared to, say, a vessel based swath system. In fact, ALBTS bathymetry is 25-30% the cost of a conventional swath survey when the economies of scale come into play. The cost break comes when site areas reach the 8-10km2 level, thereafter, the cost of a ALBTS survey compared with a conventional acoustic swath survey rapidly falls 35% at 50km2 and about 25% at 100km2.
Just as acoustic swath systems cannot do everything, so neither can ALBTS. The greatest advantages to the data user community come when the two methods are integrated. Through its international partnership program, Admiralty Coastal Surveys has developed a capacity to offer solutions tailored to individual requirements, merging the benefits of both technologies for extremely cost effective, high quality hydrographic coastal zone and shallow water survey products. When customers and user groups get together to combine their shallow water data requirements, creating larger areas, or more intensive requirements, then the economics of ALBTS for the coastal zone and shallow water environmentalist, engineer and hydrographer, becomes a realistic option for significant cost reduction and enhanced data capture.

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BIOGRAPHICAL NOTES

Edwin Danson is a Chartered Surveyor and Vice President of the Institution of Civil Engineering Surveyors and senior partner of Swan Consultants Ltd. His career spans some thirty-five years during which time he has led, or been involved with, many of the great technological advances that have transformed the hydrographic surveying profession.

In addition to some forty papers, his published works include *Management of Setting Out in Construction*, co-author, Thomas Telford Publications, 1998; *Drawing the Line: How Mason and Dixon Surveyed the Most Famous Border in America*, John Wiley & Sons, 2000; *Technology and Applications of Underwater Vehicles*, co-author, Taylor & Francis 2002; *Weighing the World: The Quest to Measure the Earth*, Oxford University Press, 2005; *Geotechnical and Geophysical Investigations for Offshore and Nearshore Developments*, Editor, International Society for Soil Mechanics and Geotechnical Engineering, 2005.

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