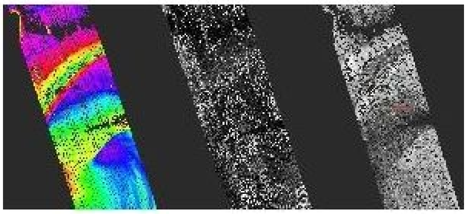
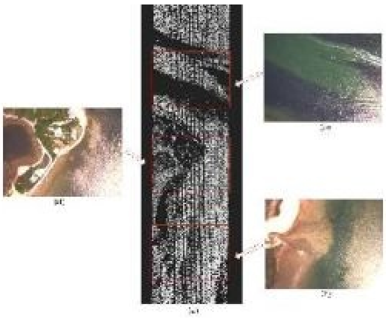
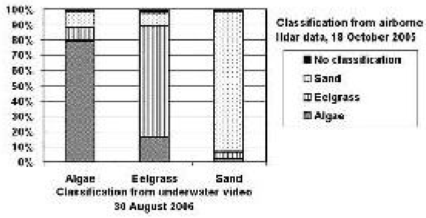
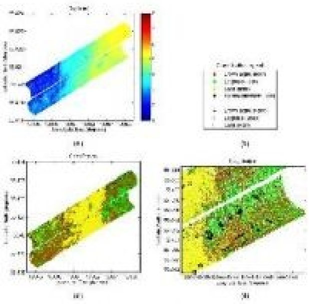
NEW APPLICATION FOR HAWKEYE II AIRBORNE LIDAR SYSTEM

Lidar Seafloor Classification









Airborne Lidar (Light Detecting and Ranging) is a well-established remote sensing technique which scans the terrain and seafloor with high-frequency laser pulses. Until now, bathymetric Lidar data has been processed to generate marine depth information and seafloor topography. However, Airborne Hydrography AB (AHAB) has developed a new method of processing data which allows information about the actual properties of the seafloor to be extracted. The accuracy and efficiency of reflectance imaging for seafloor classification is demonstrated here with data from coastal sites in both Massachusetts and Sweden.

By Xin Liu, Andreas Axelsson and H. Michael Tulldahl, Sweden.

With its advantage of high resolution and significant efficiency compared to traditional vessel-based acoustic surveys, airborne bathymetric Lidar technology has been used increasingly during the past few decades. Lidar technology has enabled bathymetric charts to be produced, underwater objects to be detected and shallow coastal areas to be monitored. A new processing technique which creates a relative reflectance image, extracted from the same Lidar data, now allows for the different types of seabed (e.g. sand, vegetation and rock) to be remotely classified.

Seafloor Classification

This article describes a technique to remotely estimate the nature of seafloor geology, e.g. sand, mud, rock, cobble or seaweed. An accurate seafloor classification is of great significance for coastal planning, geological studies or marine habitat monitoring. Although classification of the seafloor has already been widely and successfully investigated, previous studies have utilised vessel-based acoustic systems (single-beam echo sounding, side-scan sonar and multi-beam sonar). We describe here how the HawkEye airborne bathymetric system is also capable of providing seafloor character information for high-accuracy seafloor classification, with the added advantage of greatly increased data-acquisition rates and the ability to survey areas inaccessible to surface vessels.

HawkEye II Lidar

Airborne Lidar is a remote sensing technology that scans the terrain and seafloor and detects distant objects with high-frequency laser pulses. Range and other information about the distant objects are extracted from the reflected laser pulses. An airborne bathymetric Lidar system has the ability to survey a huge area (both land and sea) over a relatively short time compared to ship-based or land-based acoustic systems. Airborne Hydrography AB (AHAB) developed the HawkEye II system to meet the surveying requirements of both seafloor and land topography in the shallow coastal zone. With two laser sources, the HawkEye II system collects high-accuracy geodetic-referenced elevation data both above (infrared, 1064nm) and below (green, 532nm) the sea surface. The infrared and green lasers pulse at 8kHz and 1kHz, respectively. Combined with eight infrared and four green receiving sensors, the HawkEye II system can collect 64,000 topographic measurements (up to four returns for each shot) and 4,000 hydrographic measurements (full waveform) per second.

Reflectance Imaging

As well as being used to derive depth measurements (by measuring the difference between the green and infrared return), the size and shape of the received green waveform also provides a measure of seafloor return pulse intensity. These data are extracted from the appropriate part of the seafloor echo peak amplitude using a simple algorithm. The extracted intensity indicates the absolute reflectance of the seafloor point. However, absolute reflectance cannot be used for seafloor classification since it contains various inaccuracies. These errors can be divided into two categories: individual point systematic bias and area environmental effects.

Individual Point Systematic Bias

The offset of the laser receiver gain specified by the operator during Lidar data collection, the flight deviations (roll, yaw, pitch and heading) and the scanner angle all contribute to individual point systematic bias. To produce a normalised absolute reflectance result, the gain offset bias is compensated for in our reflectance processing algorithm. The flight deviation and scanner angle errors are corrected using the data recorded by the high accuracy Inertial Measurement Unit (IMU) and the scanner controller integrated within the HawkEye II system.

Area Environmental Effects

To produce a calibrated relative reflectance for the whole dataset, the laser energy loss through the water column must also be taken into consideration. Seawater turbidity parameters - including absorption, attenuation, scattering, backscattering and optical attenuation coefficients - are derived from the recorded green laser waveform using an algorithm developed by AHAB and the Swedish Defence Research Agency (FOI). HawkEye's post-processing software (Coastal Survey Studio) extracts local turbidity parameters for small blocks within each flight-line dataset, allowing the influence of the water column attenuation to be eliminated. Errors resulting from overlapping flight lines are corrected using a universal calibration model and high-reflectivity sample data from depths of 5-15m.

Relative Reflectance Conversion

By converting the corrected absolute reflectance to relative reflectance (ratio of individual point reflectance to the highest reflectance value within the area), a more informative description of the varying nature of the seafloor can be achieved. An example of the final deviation-corrected relative reflectance is shown in Figure 1 (right), depicted alongside the elevation data (left) and raw intensity data (middle). The distribution of the different seafloor geological bodies (e.g. sand, mud, rock or seaweed) is evident from the relative reflectance, which utilises the full range of pixel values.

Accuracy Assessment

The accuracy of the processed reflectance classification results are assessed by comparison with reference data in the form of either ground-truth data or aerial orthophotography. Ground-truth data are the most accurate and reliable and can be collected down to the complete bathymetry Lidar working depth (typically 2-3 times the visible depth). However, it is also the most expensive and time-consuming form of reference data. Assessing accuracy using aerial orthophotography is a comparatively low-cost and highly efficient method, but is limited to the near-coast shallow areas due to the limited penetration depth of sunlight. In optimum water quality conditions, seafloor information from depths of greater than 10m depth is difficult or impossible to extract from aerial photographs.

Case Study 1: South MA Coast

A comparison of the processed relative reflectance of one Lidar flight line and a few aerial photographs of the south Massachusetts coast is depicted in Figure 2. The aerial photographs were taken by the HawkEye II integrated camera while conducting the Lidar survey. As can be seen, the seafloor pattern of different geological bodies (b and c) and landscape characters (d) evident in the aerial photographs can also be clearly identified in the relative reflectance image.

Figure 3 shows the processed reflectance intensity image and the associated Google Earth aerial orthophoto of a coastal region near Boston, MA. Patterns of sediment on the seafloor can be easily distinguished from the reflectance image in the near-coast shallow area. Note that the aerial photograph cannot provide any seafloor geological information for deeper areas (approximately 8m depth in this region).

In the reflectance image, however, information on different geological bodies can still be extracted down to the working depth of the Lidar instrument (15m depth at this location).

Case Study 2: Ystad, Sweden

In 2005, a HawkEye system performed a bathymetric Lidar survey for the municipal office of Ystad and the Swedish Geotechnical Institute with the main purpose of monitoring coastline erosion in southwest Sweden. The Lidar data were post-processed by another research team who classified the surveyed areas as either sand, eelgrass or algae. The seafloor classification (Figure 4) was obtained by training a classification model and comparing with underwater video data acquired at the same site 10 months later. The overall correspondence between video and Lidar data is 82%, i.e. 82% of the sounding positions were classified similarly by both underwater video and Lidar data. The individual correspondance for dark algae, eelgrass and sand were 80%, 72% and 92%, respectively. Despite the 10 month time difference, the seafloor properties and vegetation distribution of the measured and observed data still show a high level of consistency.

The seafloor classification from parts of two Lidar flight lines and corresponding bottom depths is shown in Figure 5. The classification was performed by extracting the pulse characteristics for each selected seafloor type and assigning it to the seafloor type with the highest probability. The classified relative reflectance image shows a good correspondence with the reference data in classifying sand, eelgrass and algae.

Concluding Remarks

Since 2008, AHAB has collected and processed over 10,000 square kilometres of reflectance data using the HawkEye II bathymetry Lidar system in more than ten countries in Europe, America, Oceania, Indian Ocean and Asia. An upgraded version of the reflectance processing software with a more automated workflow is under development, and will be released in the near future. The acquisition of airborne Lidar reflectance data is a highly efficient complement to the traditional manual or acoustic seafloor reflectance technique. Combined with aerial/satellite imaging or ground-truth data, Lidar seafloor reflectance and classification products are of huge benefit within the fields of survey, coastal vegetation study, inshore fisheries and coastal monitoring.

More Information

- Anderson, J.T., Holliday, D.V., Kloser, R., Reid, D.G. and Simard, Y. 2008. Acoustic seabed classification: current practice and future directions. ICES Journal of Marine Science 65: pp 1004-1011.
- Hoge, F.E., Wright, C.W., Krabill, W.B., Buntzen, R.R., Gilbert, G.D., Swift, R.N., Yungel, J.K. and Berry, R.E. 1988. Airborne Lidar detection of subsurface oceanic scattering layers. Applied Optics 27: pp 3969-3977.
- Preston, J.M., Christney, A.C., Bloomer, S.F. and Beaudet, I.L. 2001. Seabed classification of multi-beam sonar images. In OCEANS, 2001. MTS/IEEE Conference and Exhibition, Honolulu, HI, 05-08 Nov 2001.
- Tulldahl, H.M., Vahlberg, C., Axelsson, A., Karlsson, H. and Jonsson, P. 2007. Sea floor classification from airborne Lidar data. SPIE Proceedings of Lidar Technologies, Techniques, and Measurements for Atmospheric Remote Sensing III, 6750, 675003-675001-675012.
- Tulldahl, H.M., Vahlberg, C. Axelsson, A. and Janke, H. 2008. Sea floor characterisation from airborne Lidar data. Proceedings of International Lidar Mapping Forum 08, Denver, CO, February 21-22, 2008.