Detection of Coastal Bathymetry Using Hyperspectral Imagery

Enjie Jing
Defence Science and Technology Organisation, PO Box 44, Pyrmont, NSW, Australia,
Bisun Datt
HyVista Corporation, PO Box 437, Baulkham Hills, NSW Australia

Abstract - **Amphibious landing operations require environmental information about bathymetry and seabed characteristics of littoral waters so that effective landing strategies can be planned for marine forces traversing the coastal zone. However, in certain situations, ship-based acoustic methods of surveying the environment are not practical. For example, the area of interest may be remotely located, or the survey might be required more urgently than a boat-based survey can be organised. In such situations remote sensing is an attractive alternative using airborne or satellite-based sensors.**

Recently, a hyperspectral sensing survey using the HyMap system was conducted in Jervis Bay, located about 180km south of Sydney, Australia. HyMap is an airborne hyperspectral remote sensing instrument that collects data in 126 spectral channels from the visible to the shortwave infrared wavelength regions (0.45 to 2.5 um). The bathymetry was retrieved from the sensor data by removing water absorption in depth increments iteratively until the reflectance spectrum is free from absorption effects of water. The result demonstrated that water depths up to 20m can be extracted from the hyperspectral imagery reasonably well compared with that from the conventional hydrographical survey means. Less accuracy is achievable when the water is too deep or too turbid. However, the accuracy can be improved by the use of a few ground truth measurements. The overall results suggest that hyperspectral sensing is likely to be of great value to bathymetric mapping in very shallow waters where traditional boat-based surveys are difficult, dangerous or otherwise may not be possible. With increased developments and launches of satellite-based hyperspectral sensors, there will be more opportunities for obtaining environmental information about bathymetry and seabed characteristics of large coastal water areas cost-effectively and efficiently for both military and civil benefits.

I. INTRODUCTION

A through understanding of environmental variability greatly increases the likelihood of naval mission success. Current naval operations are increasingly focused on coastal-littoral waters rather than the open ocean and involve the manoeuvre of maritime and other defence forces in dynamic littoral waters for which historical data records may be sparse or inexistent in these areas. Survey methodologies to rapidly collect data in unknown, dangerous and contested shallow territorial seas are required. The success of such operations depends on the capacity of assessing operational environment effectively and efficiently in order to gain a tactical advantage.

Hyperspectral remote sensing technology is the most recent breakthrough in passive remote sensing and has attracted much attention for both defence and civilian applications such as littoral battlefield assessment, coastal bathymetry, mineral mapping and environmental monitoring. Hyperspectral sensing instruments allow us to view the earth not only in a few, but hundreds of different spectral channels over a wide wavelength range.

Hyperspectral remote sensing has been seen by many researchers as a particularly useful means of determining inherent optical properties of coastal waters where the constituents are more complicated than those of oceanic waters. The substantial number of spectral bands for hyperspectral sensors enables spectral discrimination between different constituents within the water column and on the seabed. These additional spectral bands will enable a more accurate estimation of water depth and bottom type than was previously possible with multi-spectral remote sensing techniques.

In this paper, we discuss an application of the hyperspectral remote sensing technology for retrieving water depth from airborne-remotely sensed imagery and compare the results with those from Laser Airborne Depth Soundings (LADS).

II. SURVEY OF JERVIS BAY

Jervis Bay (Figure 1) lies on the New South Wales coast approximately 180 km south of Sydney. The deepest part of the bay is about 40 m at the entrance, which is constricted by sandstone cliffs, and is partly protected to the south by a meridional trending subsurface ridge running from the north of Bowen Island. Inside the bay the maximum depth is about 25 m towards the bay centre. A survey of the south-west and north-east parts of Jervis Bay took place on 17th August 2008, using HyMap hyperspectral scanner [1], onboard a light aircraft. The HyMap sensor has 126 spectral channels covering the VIS to the SWIR wavelength region (0.45 to 2.5 um) with a spatial

978-1-4244-5222-4/10/$26.00 ©2010 CROWN

resolution calibrated down to 3m pixel size. The flight strips have a 512 pixel swath.

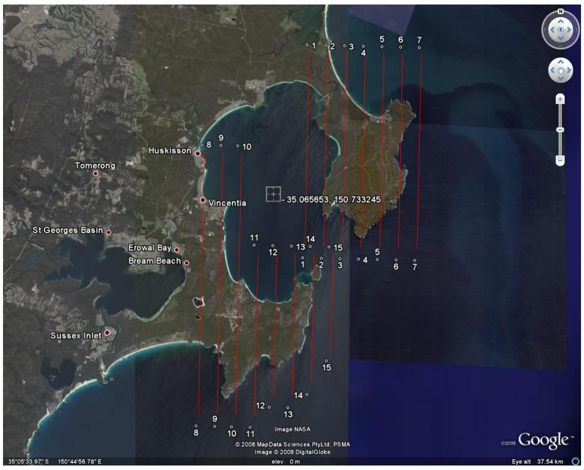


Figure 1. The survey flight lines of Jervis Bay

III. IMAGE PROCESSING

A. Atmospheric Correction

The HyMap radiance data were atmospherically corrected to surface reflectance. The ATCOR4 [2] was used for the atmospheric correction. ATCOR4 is based on the MODTRAN [3] atmospheric radiative transfer model. The scene and sensor information are automatically read from the HyMap data files, and the water vapour concentration and the aerosol optical depth (optionally) are calculated on a per pixel basis by ATCOR4 from the radiance image. For aquatic applications the output from ATCOR4 is the remote sensing reflectance. Following surface sunglint corrections, the remote sensing reflectance is easily transformed to sub-surface reflectance.

B. Sun Glint Correction

Sun glint is caused by specular reflection off the water surface and this reflected light contains no information on the water column or the seafloor. It is therefore desirable to remove the sun glint component from the reflectance data before further analysis of the data. The SWIR channels in HyMap contain mostly sunglint reflectance from the water surface, since nearly 100% of the solar irradiance is absorbed by the water column in this wavelength region and one can safely assume that no water leaving radiance is present. The only signal contributions would come from atmospheric scattering or reflected from floating surface materials. Base on such theory, the sunglint correction used the 2.1 um channel as the sunglint reference, and the sunglint component for all the other channels was calculated using their relation with the 2.1 um channel based on atmospheric transmittance.

Figure 2 shows the reflectance profile across a flight line for one of the VIS bands before (green line) and after (white line) sunglint correction.

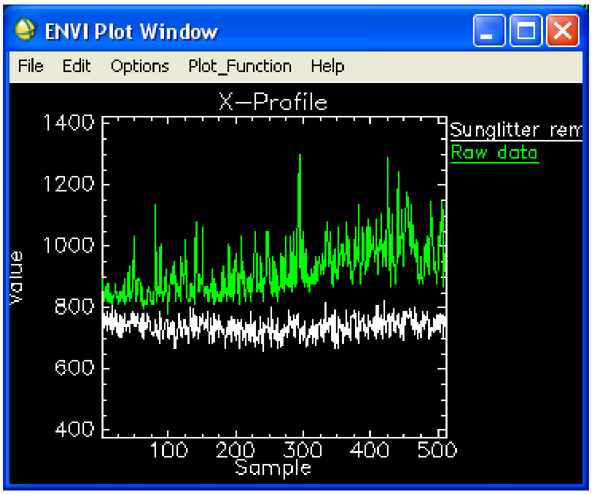
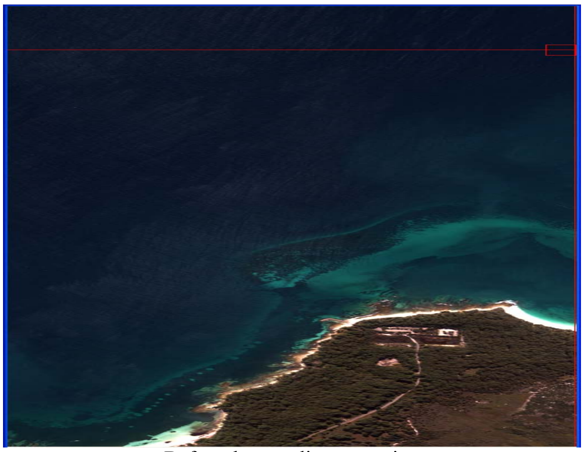


Figure 2. The reflectance profile of JB-L13 for one of the VIS bands before (green line) and after (white line) sunglint correction.



Before the sunglint correction

After the sunglint correction

Figure 3. Top - True colour images with sunglint uncorrected; Bottom – True colour image with sunglint corrected.

For the Jervis Bay data the main sun glint component was due to randomly oriented wave facets, as indicated in the 'before' and 'after' true colour images in Figure 3. The more intense sun glint caused by alignment of sensor look angle with the specular reflection angle was avoided by the North-South flight lines used for this Southern Hemisphere winter scene.

C. Bathymetry Extraction

The radiative transfer model for shallow waters proposed by [4] was used for bathymetry retrieval. This model relates the sub-surface remote sensing reflectance to the scattering and absorption by water, suspended particles (SP), dissolved organic matter (CDOM), and phytoplankton pigments (CHL), the bottom albedo, water depth, and the subsurface solar and viewing angles. For the inversion of the model the published values [4] of absorption and scattering coefficients for water, SP, CDOM and CHL were used. For the concentrations of SP, CDOM and CHL, typical values for clear coastal waters were input to the model.

The inversion of the model required the retrieval water depth using the above inputs as well as the unknown value of bottom albedo. In order to solve the inversion equation with two unknowns; an iterative procedure was used whereby the bottom albedo was calculated for depth increments of 0.1m between the 0-40m range. The correct water depth for each pixel was determined when the bottom albedo spectrum showed no absorption features of liquid water. This was determined by matching the shape of the derived albedo spectrum at each depth increment with the original spectrum (i.e. the correlation versus depth plot was used to determine the critical depth).

The algorithm also accounted for the fact that with increasing depth the bottom albedo is derived for fewer spectral bands in the visible wavelengths. For example at water depths of 0.2m the bottom albedo up to 18 channels in the 0.45-0.70 um wavelengths can be retrieved, while at 20m depth only the first 5-6 channels in this wavelength range are retrievable. This inversion technique allowed the bathymetry calculation directly from the image data with no known depth or bottom albedo information required.

IV. RESULTS

Figure 4 shows a horizontal transect of the HyMap survey of Jervis Bay and the bathymetry derived from the HyMap data, also compared with the water depth from LADS of the same transect. A close correlation between the hyperspectral bathymetry and the water depth from LADS can be seen.

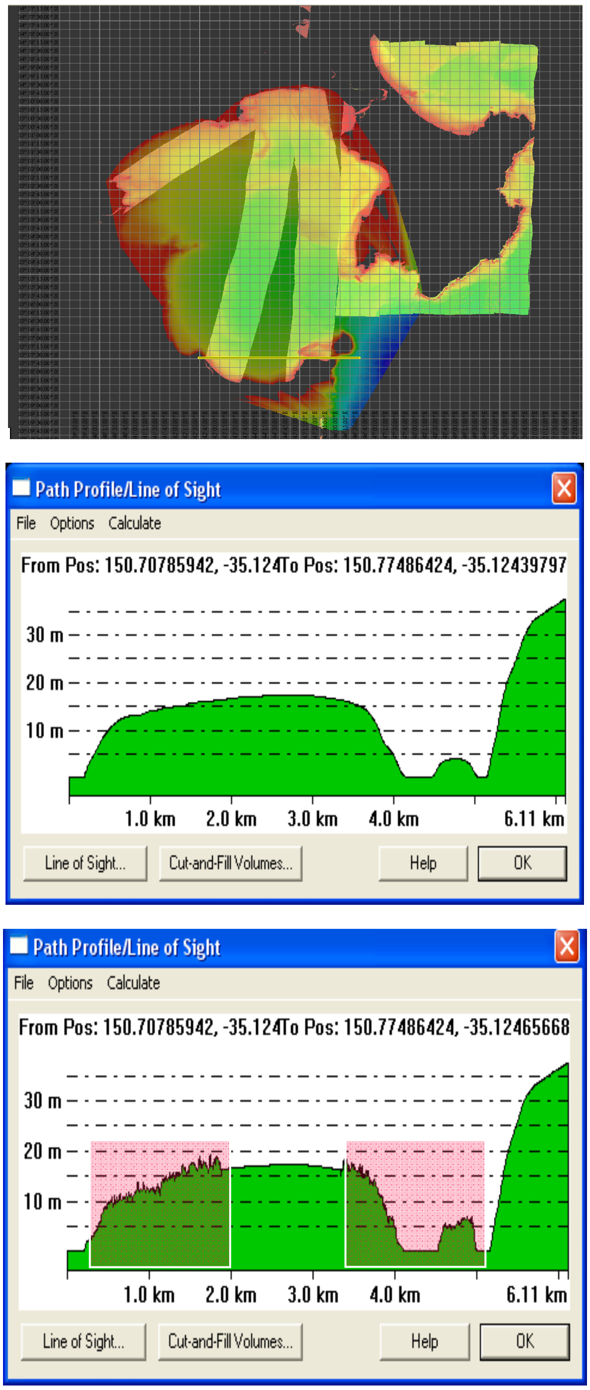


Figure 4. Top – A horizontal transect of the HyMap survey of Jervis Bay; Middle – Bathymetry from LADS; Bottom – Bathymetry retrieved from HyMap imagery and LADS combined.

Figure 5 illustrates an area or subset of the bathymetry retrieved form the HyMap imagery and a comparison with the water depth from LADS. Once again, the result shows that that the water depths derived from the hyperspectral imagery have a very high correlation with those from LADS up to a depth of 20 metres. In the near-shore region, the results are even more reliable.

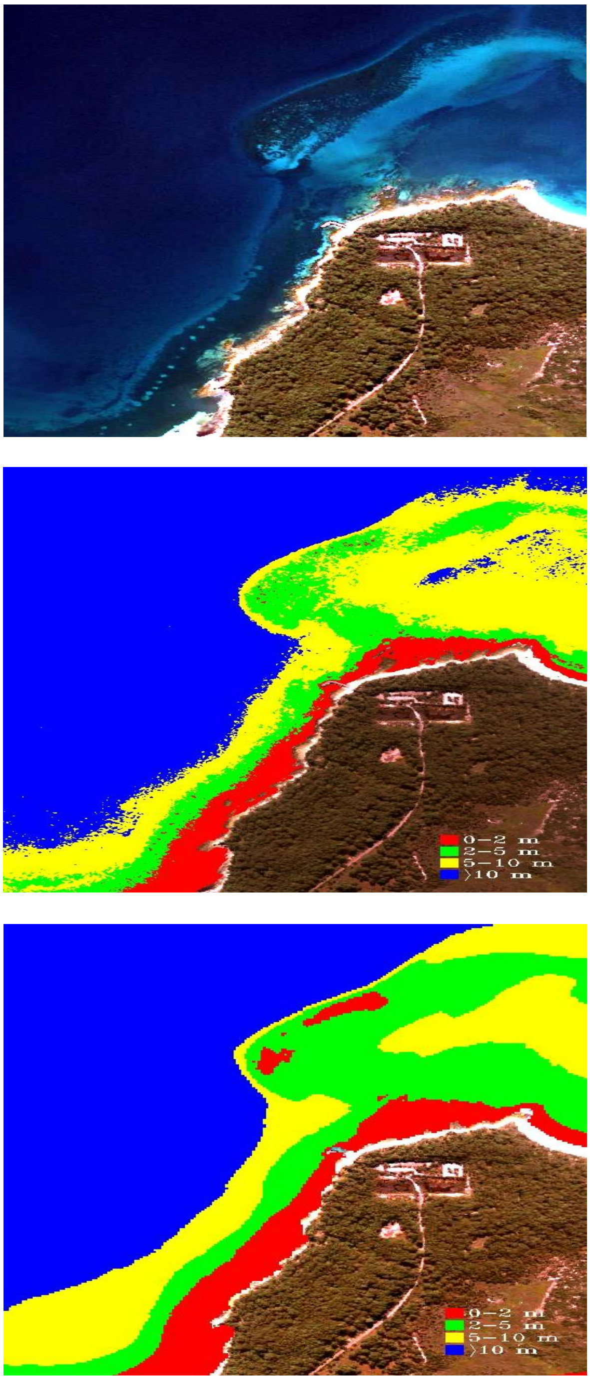


Figure 5. Top – Hyperspectral true colour image of Jervis Bay; Middle - Bathymetry retrieved from HyMap imagery; Bottom - Bathymetry from LADS.

Some errors are sparsely distributed and visible in the region of water waves and white caps near the entrance of the Bay. Hence it is suggested that conducting such a survey in calm sea state condition is desirable.

At greater depths where the water is considered optically deep or in turbid waters, the derived water depth from the HyMap imagery may become less correlated with LADS. However, the accuracy can be improved by the use of a few ground truth measurements. Techniques are under development to acquire bathymetry of shallow water, and to identify objects in the surf zone directly from hyperspectral imagery without a requirement for depth or bottom albedo information.

V. CONCLUSIONS

The results of the hyperspectral sensing of Jervis Bay have demonstrated that water depths up to 20m can be extracted reasonably well compared with that from LADS. However, less accuracy is achievable when the water is too deep or too turbid. The overall results suggest that hyperspectral sensing is likely to be of great value to bathymetric mapping in shallow, littoral waters where traditional boat-based surveys are difficult, dangerous or otherwise may not be possible. With increased developments and launches of satellite-based hyperspectral sensors, there will be more opportunities for obtaining information about bathymetry and seabed characteristics of large coastal water areas cost-effectively and efficiently. Whilst this data does not produce the International Hydrographical Organisation (IHO) standard charting, it is a valuable technique for Rapid Environmental Assessment.

ACKNOWLEDGEMENTS

This work is supported by the Defence Science and Technology Organisation. HyVista, the owner of the HyMap sensing instrument, was contracted to carry out the survey.

REFERENCES

[1] T. Cocks, R. Jenssen, A. Stewart, I. Wilson and T. Shields, the HyMap Airborne Hyperspectral Sensor: The System, Calibration and Performance, EARSEL Workshop on Imaging Spectroscopy, Zurich, October 1998.

[2] Richter, R., Schlapfer, D., and Muller, A., An automatic atmospheric correction algorithm for Visible/NIR imagery, International Journal of Remote Sensing, Vol. 27, No. 10, pp 2077-2085. 2006.

[3] Berk, A., et al. "MODTRAN4 Version 3 Revision 1 User's Manual", Air Force Research Laboratory, Hanscom MA (2003).

[4] Z. Lee, K. L. Carder, R. G. Steward, and J. S. Patch, Hyperspectral remote sensing for shallow waters: 2. Deriving bottom depths and water properties by optimization; APPLIED OPTICS, Vol. 38, No. 18, 20 June 1999.