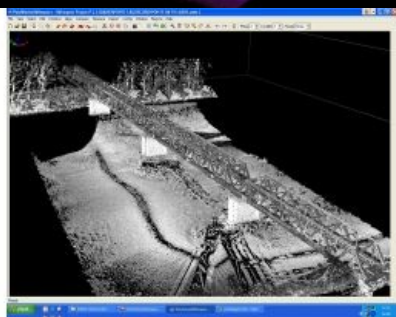
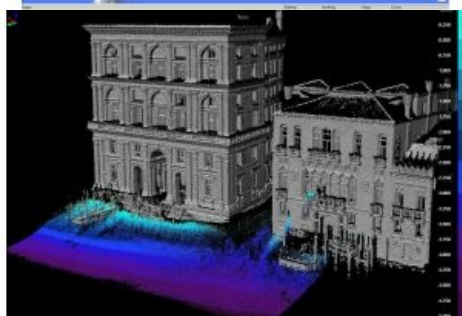
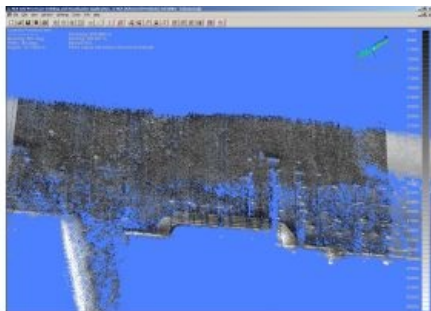


Waterside Mapping



Laser scanning and bathymetric side-scan sonar represent the cutting edge of environmental survey technology. Over the last few years, we have tested the integration of these two methodologies, carrying out a number of high-resolution surveys on the Po River, the Venice canals and various Italian harbours.

Bathymetric surveys were conducted using a SEA SWATHplus-H wide-swath sonar. An Optech [ILRIS-3D](#) terrestrial laser scanner was used to scan the areas above water level. Information from these scans was used to create 3D black and white images (intensity images) of the surveyed area. In the case of the laser scanner, these images are pseudo-photos based on the response to the infrared reflectivity of the different materials, whereas for SWATHplus it is the intensity produced from a real side-scan image. The similarity of the data provided by the two systems (point cloud and intensity value) makes it easy to integrate the two surveys using PolyWorks commercial software. The final product is a single 3D model made up of bathymetry and topography. It is possible to add digital camera images to this model for a 3D photo-realistic view of the surveyed area.

The Technology

SWATHplus is a well-established commercial bathymetric side-scan sonar for marine underwater mapping, and can be installed in a variety of boats. SWATHplus seamlessly integrates motion sensing and GPS systems to correctly georeference soundings of the seabed. It is well suited to shallow-water surveys, typically achieving swath widths of 10 to 15 times water depths up to 30 metres. In contrast, the ILRIS-3D is a ground-based (tripod-mounted) laser scanner that can be used to conduct surveys from distances of 3 metres to more than 1,500 metres. Recently though, firmware enhancements (ILRIS-MC) allow the Optech's Laser Scanner to interface with a GPS/IMU sensor so that surveys can be undertaken on a mobile platform. This will provide the capability of performing both surveys from the same platform at the same time, reducing survey and processing time and increasing accuracy. The SWATHplus and ILRIS-3D both offer several advantages compared with traditional survey techniques: surveys can be completed day or night, even in heavily shadowed areas; and data collection and turnaround time are both faster and cheaper (data processing is semi-automatic) than for traditional surveys.

ILRIS-3D

The Optech ILRIS-3D is a terrestrial laser scanner. The main principle on which laser scanning, or LIDAR (light detection and ranging), technology is based is the calculation of the time of flight of a laser pulse. LIDAR works similarly to ordinary radar, except that LIDAR systems send out narrow pulses or beams of light rather than broad radio waves. A receiver system times, counts and processes the returning light. Using the speed of light – approximately 0.3 metres per nanosecond – the system calculates how far a returning light photon has travelled to and from an object. The system records the Cartesian coordinates XYZ of every measurement as well as the intensity of the beam, dependant on the object's level of reflectivity.

SWATHplus

The SEA SWATHplus is a wide-swath bathymetric side-scan sonar that uses the phase difference measurement technique (commonly known as interferometry). The term 'interferometry' is generally used to describe swath-sounding sonar techniques that use the phase content of the sonar signal to measure the angle of a wave-front returned from a sonar target.

The wet-end hardware consists of two transducers, one facing port and the other starboard. Each transducer has five horizontal arrays (or 'staves'). Each array produces a beam that is narrow in azimuth (i.e. viewed from above), and wide in elevation (viewed from the side). One of the staves transmits a pulse of electrical energy at the sonar frequency, producing a narrow 'shell' of sound that moves outwards from the transducer. Where the pulse meets the seabed, there is a small 'ensonified' patch; this patch also moves outwards. The ensonified patch scatters sound energy in all directions. When this scattered sound is detected back at the transducers, the phase difference of the signal at the four receiver staves is used to calculate the angle; the amplitude of the signal is used to record the back-scatter strength. The speed of sound in water is approximately 1,500m/s. Using this, the range is calculated from the travel time there-and-back. The range and angle pair enables the location of the sounding to be known relative to the sonar transducer.

SWATHplus requires accurate positioning and motion information to convert the soundings into a georeferenced data set. An Octopus F180 was used for these trials. The F180 uses dual GPS antenna and motion-sensing technology. It has inertial sensing capabilities for a fully integrated single solution for positioning, orientation and motion. The dual frequency (L1/L2) system, when aided by real-time kinematic (RTK) corrections, can provide very accurate height information that can be used to provide 'real-time tide' information. The F180 data was RTK-corrected with corrections being provided by a Thales Z-Max GPS.

The Survey Areas

Trial surveys were carried out to test the integration of the different sensors. The trials were conducted at a number of separate locations chosen to demonstrate the abilities of the systems. Each area is briefly described and illustrated (see Figures 3 to 5).

Po River

The area was surveyed in order to obtain a complete bathymetric picture of the wharfs and river banks. The survey was run bank to bank, totalling an approximate 7km section of the river over a period of 6 hours. The river width varied between 100 and 500m in the survey areas, and was generally 200–300m wide. The bulk of the channel was surveyed in four lines. There were two bridges within the survey area, one of which was scanned using ILRIS-3D using four ground station points around the bridge, two per side over the bank. Figure 3 shows the bridge in relation to a section of the river.

Venice Grand Canal

In Venice, the Grand Canal was surveyed bank to bank in two passes in approximately 3 hours. The main focus of the laser scan survey was the localisation of the poles in the front of the building. The building was surveyed from the opposite bank using an ILRIS-3D scanner with two scans in approximately 20 minutes. The continual vibration and instability of the bank forced the survey to be completed quickly.

Livorno Harbour

The survey of the Livorno Harbour was conducted in two phases. The SWATHplus survey was used to produce bathymetric digital terrain model (DTM) and side-scan images of the harbour. Later, the laser scanner survey resulted in the analysis of the structure of the castle. Figure 6 shows a section of the castle walls leading into the harbour. A number of wrecks and vessel moorings can be seen in the bathymetry.

Data Processing

With the ILRIS-3D, every scan has its own reference system relative to the survey point and the creation of the solid model is dependent on the merging of all scan data using one reference system to create commonality. The software used for this application and for general data processing is IMAAlign by PolyWorks. This software allows the selection of a natural point to connect various scans (through some common recognisable features on the object surveyed such as house corners, identifiable geometry and different reflectivity of the walls). By using IMAAlign, data collection in the field is easier and faster because natural common points of reference are used to georeference the scans rather than installing artificial targets. The various scans are aligned by selecting three or more common points present on both of the two adjacent scans. These points, whose position is known in their respective reference systems, constitute the basis on which the scans are aligned; using iterative closest point (ICP) algorithms, the software recognises 'homologue' points and performs a spatial rotation and translation without scale variation with respect to the reference system of the adjacent scan. It estimates six independent parameters: the three rotations around the XYZ axis and the three spatial translation parameters.

In this way, IMAAlign estimates the orientation and generates a roto-translation matrix for each scan. This process is applied to each scan and creates a complete solid model of the object surveyed.

SWATHplus has its own software for data cleaning and DTM production. The RTK position data, the motion sensor data and SOS profiles are applied to the sonar data to fully georeference the data set. RTK height or tidal values can be used to provide height control for the bathymetric data set. The final model can be exported as an XYZ point cloud with side-scan intensity and merged with the ILRIS-3D data set using the IMAAlign tool. The PolyWorks IMInspect tool provides the user with the capability to visualise the data from any perspective, with data points being rendered with a height/depth colour map, intensity value or photographic/side-scan GeoTIFF image. It is also possible to extract cross-sections through the data to study morphology changes by comparing future surveys in the same areas.

Conclusions

The combination of 3D laser scanning and side-scan sonar can be extremely beneficial when mapping complicated areas. It is important to consider the following issues:

- It is difficult to plan the exact overlapping zones for the two platforms. When artificial targets are impractical, it is necessary to ensure that both scans show some easily recognisable natural elements. However, the georeferencing of the laser point cloud does speed up processing and merging of the bathymetry data set. In certain situations, this issue may be overcome if the scanner is mounted directly on the boat and interfaced to the same positioning system used by the bathymetry system. This solution was, however, not available at the time of our tests.

- The different resolutions and accuracies of the two technologies means that the bathymetric survey (which works with sound under water) has a much lower resolution and accuracy than the laser scanner (which works with light).

It is clear from the surveys that the two systems can be considered to be complementary to each other. In conditions where neither technology can excel independently, by working together the two provide a complete data set. In these surveys, the fusion of these two methods generated a complete and accurate digital model of different areas above and below the water level – a result that cannot be duplicated with any other topo-graphical survey instruments.

Acknowledgements

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Further Reading

- Bates, C.R., and P.W. Byham, 2001: Bathymetric Sidescan Techniques for Near Shore Surveying. The Hydrographic Journal , 100.
- Codevintec, 2006: Batimetria Interferometrica, Laser Scanner e Side Scan Sonar integrati. Presented at the Optech 2006 Seminar.