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THE APPLICATION OF SATELLITE IMAGERY IN SUPPORT OF NAUTICAL CHARTING; PAST EXPERIENCE AND FUTURE POSSIBILITIES. A PRACTICAL VIEW

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ABSTRACT

This paper sets out to give a practical overview of how satellite imagery has been used to date in the UKHO and its likely future use in support of nautical charting. It is concerned only with commercially based digital systems. Systems designed primarily for defence purposes are not included. It should be noted that the views expressed herein are the result of the author's own experience and do not necessarily represent the current official policies of the UKHO.

INTRODUCTION

Following a period of research in the early 1980s, the UKHO began using Satellite Imagery as a data source routinely in 1987, in areas where up-to-date information was unavailable or difficult to obtain. The following advantages of acquiring information by remote sensing apply, irrespective of platform or sensor;

1) It is cheaper than conventional surveying;

2) It is safer than hydrographic surveying in shoal areas such as coral reefs;

3) It is capable of change detection in rapidly developing ports and regular monitoring of mobile areas such as deltas and sandbanks;

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4) World-wide cover is commercially available, without security, political, or copyright restrictions;

5) The inherent geometry and therefore the relative positioning of features within a single scene is generally very good.

Over ten years, the UKHO has successfully improved charts at scales of 1:25,000 and smaller, using data from a variety of sensors.

In order to appreciate the benefits of using satellite imagery, it is necessary to describe briefly the sensors in use.

PASSIVE SENSORS

Passive electro-optical (EO) sensors measure solar energy reflected by the earth's surface, using multi-spectral scanners. They are sensitive to visible and near infra-red light and operate in daylight. The factors which differentiate the various systems are their respective spatial, spectral and radiometric resolutions.

Spatial resolution refers to the size of the pixel or picture element. This defines the size of objects which can be identified from the data and thus the scale of charting which can be supported.

Spectral resolution refers to the number of independently scanned wavebands of the useful (visible and near infra-red) section of the electro-magnetic spectrum which can be simultaneously imaged.

Radiometric resolution refers to the number of shades between black and white within a grey-scale image or spectral band. This is governed by the number of bits per pixel which can be recorded. For example 8 bit data has 256 shades of grey.

THE SENSORS

Landsat's Multi-Spectral Scanner (MSS) records four 6 bit raster images of each scene, in the green and red visible light bands and two near infra-red bands. Each image covers an area of 185 x 185 km, with a spatial resolution of about 80 metres.

Landsat's Thematic Mapper (TM) scanner records seven 8 bit raster images of each scene, in the blue/green, green and red visible light bands and four infra-red bands. Each image covers an area of 185 x 185 km, with a spatial resolution of 30 metres.

SPOT's High Resolution Visible (HRV) push-broom scanners record an entire line of image data simultaneously across the track of the satellite for higher geometric and radiometric accuracy. The HRVs operate in either panchromatic or multi-spectral mode.

In panchromatic (PAN) mode the SPOT sensor records a single 8 bit raster image of 60 x 60 km with a spatial resolution of 10 metres.

In multispectral (XS) mode the sensor records three 8 bit raster images corresponding to green & red visible light and one near infra-red band. This also has a 60 km square "footprint" but the spatial resolution is 20 metres.

Each channel or waveband recorded by the sensors was chosen for its value in identifying substances of scientific interest.

Below are some examples of use in charting.

CHANNEL	VALUE
Blue/green	Penetrates clear water therefore sub-surface features can be seen
Green	Reflected by healthy vegetation/ turbid (muddy) water. Some penetration of clear water
Red	Absorbed by vegetation
Near infra-red	Absorbed by water, therefore ideal for coastline delineation. Reflected by healthy vegetation
Mid infra-red	Indicates moisture. Helps to differentiate snow and clouds (snow is dry, clouds are wet)

These sensors have been the most useful for nautical charting to date.

THE SATELLITE SYSTEMS

The passive sensor bearing systems have in common near-polar, sun-synchronous orbits at altitudes in the 700-950 km range. The satellite path moves westwards each day, each orbit of the earth taking about 100 minutes and passing over the Equator at approximately 10:30 local solar time. A satellite path is repeated every 16-18 days in the case of Landsat and 26 days for SPOT. Data is collected and transmitted continuously during the north-south or descending path. This is recorded by a network of receiving stations strategically placed around the globe to give maximum earth coverage.

Landsat 1, launched in July 1972, was the first unmanned Earth resources satellite. It was followed in 1975 and 1978 by Landsats 2 and 3. All three carried the MSS, which successfully recorded thousands of scenes.

Landsats 4 and 5 were launched during the 1980s and improved on the performance of their predecessors by carrying the TM scanner as well as the MSS.

In 1986, the first French "Système Probatoire de l'Observation de la Terre" (SPOT) satellite was launched. Subsequent satellites followed in 1990 and 1993.

SPOT sensors can be programmed to view up to 27 degrees off nadir (obliquely), giving repeat cover every 1 to 5 days, depending on latitude. (This oblique viewing capability also allows production of stereo pairs of images).

The SPOT satellite can also be programmed to record data onto magnetic tape for later down-loading whilst it is out of range of the receiving stations.

DATA ACQUISITION AND USES

Prior to imagery purchase, the UKHO requests a data search of all archived images of the particular location required. The most suitable image is then selected; cloud cover and acquisition date being the prime considerations. The tidal level at the time of imagery can also be determined if needed. A small scale low quality image or "quick look" is obtained to confirm the choice of scene. Data is now supplied in digital form on CD-ROM, (though it was formerly supplied written to film and is still used in this form when appropriate).

Landsat MSS 80-metre data is useful for scales smaller than 1:200,000.

Landsat TM 30-metre data is appropriate at scales of 1:100,000 and smaller.

SPOT imagery is best at scales of 1:50,000 and smaller. However, in areas where the land/water contrast is good it is possible to capture useful information at scales as large as 1:25,000.

IMAGE PROCESSING

Commercially available data can be processed to various levels prior to purchase. The UKHO buys 'system corrected' data, which means that geometric, radiometric and sensor errors (and for SPOT data, errors due to the earth's curvature), have been eliminated. (Earth curvature errors arise with SPOT data because of its ability to view off nadir).

Satellite imagery is initially referred to the Space Oblique Transverse Mercator projection, which gives a reliable fit to a Transverse Mercator projection. It is used primarily, however, to support medium and small scale charting on the Mercator projection.

The data, where possible, are geo-referenced using the UKHO's extensive geodetic library. The inherent geometry of system corrected data has proved to be sufficiently accurate for most of our purposes, as in many cases we are concerned primarily with the relative positions of features within the raster. However, geo-referencing enables us to refine the data geometry and position the raster in absolute terms. This has the advantage that information derived from the raster by digital processing is also geo-referenced and can be transformed to any map projection.

Information derived from non geo-referenced rasters is positioned by reference to other graphical information (such as maps or surveys) during the compilation process.

Care in the choice of ground control points is vital as there is the constant danger of corrupting rather than refining the geometry of the dataset. For example, we were requested to delineate and position the edge of the coral reef encircling Bermuda. The required detail was at a considerable distance outside the six control points on the island. A manual four parameter shift (in x, y, rotation and scale), to best fit the image to the charted coastline, was preferable to a polynomial warping of the raster to fit the six control points.

INTERPRETATION AND ANALYSIS

Satellite image interpretation is the natural successor to air photo interpretation and many of the same techniques are used. There are, however, some very significant advantages in handling digital data. Some of these advantages derive simply from the processing methods and could be applied to scanned air photographs. The key advantages, however, derive from the high spectral and radiometric resolution inherent in the data captured by the sensor.

IMAGE MANIPULATION

Contrast Stretching

Contrast in an image is defined by the range of brightness levels recorded.

The SPOT & Landsat sensors are capable of differentiating between many more brightness levels than the human eye or photographic film. They have to be capable of recording radiance levels from all parts of the earth, from bright desert to dark forest. Therefore sensors record many scenes which have considerably fewer shades of grey than the sensor is capable of recording and have many similar shades from one part of the spectrum. Stretching all or part of the recorded data over the full range of shades available considerably enhances its appearance and utility.

Contrast stretching gives the image analyst the opportunity to enhance the image to suit the requirements of the task in hand. One of the most valuable uses of this technique is in the interpretation of underwater detail. Various linear stretches are applied to provide separation between different types of feature. In clear water, bottom features are visible down to about 30 metres.

Colour Composites

For more general interpretation a colour image is sometimes an advantage. To achieve this, three bands of a multi-spectral scanner scene are selected, contrast stretched individually and then combined to produce a natural or false colour composite.

False Colour Composites (FCC) are created by displaying the visible green band as blue, the visible red band as green and the infra-red band as red. This gives an image similar to a photograph taken using false colour infra-red film. Healthy vegetation appears red because it reflects most of the infra-red light falling onto it, water appears blue, deepening to black and clouds appear white. This is useful in identifying islets covered in healthy vegetation on scenes with patchy cloud cover.

Natural colour composites can be created using Landsat TM by displaying the visible light bands with the appropriate colours. Familiarity is a valuable aid to interpretation.

HYDROGRAPHIC INFORMATION GENERATION

When the satellite data has been geo-referenced and contrast stretched, interpretation and information capture can begin. A Computer Aided Design (CAD) file is referenced to the raster. Information is then interpreted and digitised in this file by an experienced compiler. The following features are normally derived from satellite imagery;

Coastline is derived using the high land/water contrast of the near infra-red raster.

Drying line, dangerline, isolated dangers and a limit of visible bottom are interpreted from the blue/green raster. Approximate depth contours may sometimes be inferred from the blue/green raster.

Much work has been done to establish the relationship between pixel brightness and water depth to facilitate the capture of bathymetric contours from imagery. Our experience so far suggests that results are not consistently accurate enough for large or medium scale navigational charting. The technique is unreliable as many factors other than water depth, for example suspended sediment or changes in the nature of the bottom, affect pixel brightness. The difficulty of field checking in many of the areas in which we are using imagery restricts further exploration of this technique.

Any valuable topographic information and large features which may be useful as navigational aids are also digitised. These include oil tanks, large buildings, wharves, jetties and other port installations, tanker mooring buoys, roads, railways and sometimes dredged areas and pipelines. Features which cannot be identified absolutely can often be interpreted by reference to other source documents and by experience. A background in chart compilation is therefore essential. The resulting file is finally output to a drum plotter and used in the chart compilation process.

RESTRICTIONS/LIMITATIONS

Although passive remotely sensed imagery can provide valuable data for charting purposes, it has limitations.

Prime among these is the problem of absolute positioning of features on the ground without reference to ground control points. In remote or unsurveyed areas, the very places where imagery can provide new information, this ground control is at best limited. This situation will improve as satellite orbit parameters and attitude are more accurately controlled.

The second limitation is that of spatial resolution. Even the 10-metre resolution of SPOT PAN imagery is not sufficient to detect small features (such as pinnacle rocks, navigational buoys, beacons and masts), which may be either hazardous or useful aids to mariners. This is also likely to improve, as a result of customer demand for increasingly high resolution data.

Thirdly, cloud cover can limit the amount of detail visible on an image, or hinder interpretation. Energy from the visible and infra-red part of the spectrum cannot penetrate cloud and some areas of the world are almost continually cloud covered. The solution to this problem lies in a completely different type of system, known as an Active System.

ACTIVE SYSTEMS

An active system transmits a narrow beam of microwave energy and measures the reflected signal. The method of operation is similar to that of ship-borne sonar.

Synthetic Aperture Radar (SAR) uses a short antenna and a complex pattern of microwave transmission and reception to simulate a real aperture radar with a very long antenna system. This permits the SAR sensors to observe the earth, day and night, from a similar altitude to the passive sensors discussed earlier (785 km) and still provide high quality data.

The microwaves transmitted by SAR are of much longer wavelength than visible light. This gives SAR the valuable ability to "see through" clouds.

Instead of looking straight down, SAR systems transmit their signal obliquely, causing positional discrepancies due to relief. Therefore, mountains appear to lean over but coastline, being of constant elevation, is positionally unaffected. However, in areas of extreme relief it can be completely or partially obscured by this "layover" effect. The radar shadow behind areas of high relief can also obscure the coastline.

If two SAR images covering the same area, one in ascending mode and one in descending mode, can be acquired, the problems caused by "layover" and shadow can be largely removed.

EXAMPLES

1) Gulf of Suez

Image-plots in the Gulf of Suez were prepared at scales varying from 1:30,000 to 1:150,000. The only known ground control points were oil installation coordinates. Horizontal control plots (HCPs) with the same scales and corner coordinates as the planned new charts were prepared. All the required hydrographic information including the oil installations was captured from the most appropriate imagery and output at chart scale. The satellite derived information was then manually fitted to the HCPs by correlating the common oil installations.

2) Nile Delta

In 1992, the HO received a report that a lighthouse marking the entrance to the Rosetta Mouth of the Nile had apparently been moved inland. It seemed more likely that the coastline had been eroded. A SPOT PAN scene dated 1991 confirmed the erosion and showed that the coastline was approximately two miles S.E. of its original position. Charts were corrected by Notice to Mariners block.

3) Marguerite Bay, Antarctic Peninsula.

Plots at a scale of 1:150,000 are being prepared. HCPs have been plotted, using control points established over the last 40 years by HMS Endurance and British Antarctic Survey. The control points have been identified using aerial photography and their positions transferred to the imagery.

In this region the large distances between control points make satellite imagery essential for deriving and positioning detail over large areas. Only coastline can be derived from the imagery and referenced to the HCPs, but the plots will later be enhanced using aerial photography.

Even deriving the coastline in the Antarctic from imagery can be difficult, due to the presence of ice. For example, pack ice can obscure the coastline, glacial advance or retreat can cover or reveal detail and icebergs and ice covered islets are sometimes impossible to tell apart.

4) South Orkney Islands.

It had been known for some time that substantial errors in coastline shape and position existed in the South Orkney Islands, but persistent cloud cover prevented acquisition of "passive" imagery. The availability of SAR imagery from ERS-1 (the European Remote Sensing Satellite launched by the European Space Agency in 1991) allowed us to correct some of these errors.

The geometric accuracy of the ERS-1 SAR scene was proved to be better than 25 metres; certainly accurate enough to provide a plot which was to be the basis for a chart at 1:200,000.

The image was scaled photographically, then fitted to a HCP, prior to plotting the coastline. Four Doppler points from our geodetic archive were included on the HCP, identified on photography and transferred to the film copies, to control positioning. The plot was incomplete because it was impossible to identify the coastline in places, but a later plot, from SPOT imagery, of part of the coastline which was cloud free, confirmed the interpretation from ERS-1 SAR and infilled some of the gaps.

5) (Ab_ aby), United Arab Emirates.

The commercial availability of current data enables us to keep up with rapidly developing ports.

SPOT XS imagery was used to update existing charts of Ab_ aby, at 1:32,500, for extensive new port development. The image was particularly clear and the land/water contrast was high.

The geometric fidelity of the SPOT scene also revealed some positional discrepancies in two smaller scale charts. These will be resolved for the next editions of these charts.

THE FUTURE

From the UKHO point of view the most important development taking place is the imminent launch by Space Imaging EOSAT of the Ikonos series satellites, with sensors capable of producing data of 1 metre spatial resolution.

Ikonos 1 is due for launch in March 1998, Ikonos 2 should follow at the end of 1998. They will each have a sun-synchronous near polar orbit at an altitude of 680 kilometres and will be capable of imaging in panchromatic or multispectral mode. The satellite is designed to produce images with a positional accuracy of +/- 4m without ground control, improving to +/- 2m with ground control.

The opportunity to consistently refer plots of areas with no known ground control to WGS 84 Datum with at least 4m accuracy will be of enormous significance to both paper and electronic charting. (Thirty-five percent of current Admiralty charts which carry satellite-derived positions notes caution that the shift between chart datum and WGS 84 Datum cannot be determined).

If 1-metre resolution data can be obtained for several key locations within an area and accurately geo-referenced, the rest of the area could be completed using existing types of imagery.

In addition, 1-metre data will enable us to identify or interpret detail not visible on current imagery, making plots more complete. It will provide an ideal bridge between aerial photography and currently available imagery.

Along track stereo will facilitate digital photogrammetric techniques, allowing us to measure elevations or create Digital Terrain Models.

Other high resolution satellites, such as Earthwatch's Earlybird and Quickbird and SPOTs 4 and 5 are also due for launch in the next few years.

CONCLUSIONS

Satellite imagery is a valuable tool in chart compilation. When geo-referenced to known ground control it can provide an accurate picture of coastline, drying and shoal areas and a reliable framework on which to compile the rest of the chart detail. Higher resolution imagery can also add significant navigational information.

Even without geo-referencing, imagery can be used for the relative positioning of detail.

Imagery could be used to examine routes into ports and eliminate unsuitable ones, thus reducing hydrographic surveying costs by highlighting the areas on which to concentrate.

As satellite technology improves, the value of imagery in chart revision and compilation will increase. Improvements in processing hardware and software will add further versatility. As always, new techniques will be evaluated, benefits and reliability being weighed against costs. Satellite imagery has been described in the past as "an answer looking for a question". I believe that it will provide the answers to many more questions of navigational significance in the near future.

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