SATELLITE IMAGERY AND ITS APPLICATIONS TO OFFSHORE MAPPING IN AUSTRALIA

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ABSTRACT

Terrestrial imagery obtained by scanners aboard the U.S. LANDSAT series satellites has already found application in a multitude of programs of earth resources enquiry. A description of the Landsat system and details of the multispectral scanning sub-system serve to introduce the applications of this imagery to mapping in general and to the Division of National Mapping's bathymetric program in particular.

Imagery obtained at satellite altitude over ocean-water areas enables the identification of shallow water features such as islands, coral reefs and shoals. The shortage of existing maps of many offshore areas suggests the use of the imagery in these regions. The planimetric accuracy of the imagery, problems of improving the geometric fidelity, and the methods by which shallow water depth information can be extracted from the scanner data are discussed during a review of the use of this information for bathymetric mapping purposes.

LANDSAT SATELLITE IMAGERY

Introduction

Following the success of the Gemini and Apollo manned spacecraft programs in proving the application of photography and other remote sensing of the earth's surface from space, the United States National Aeronautics and Space Administration (NASA) embarked on a Post-Apollo program to continue its experimental studies of the usefulness of multispectral imagery from space to earth resources applications.

The advantage of multispectral imagery lies in the separation of individual features afforded by recording narrow band widths in the visible (380-700 nanometres:nm) and infra red (700+nm) portions of the spectrum. These recordings can be reproduced on photographic film either separately or in combinations of colour to assist interpretation of resource data.

Apart from the Skylab manned missions which extended these experiments with further recoverable film and other sensor information, the major activity related to the Earth Resources Technology Satellite (ERTS) program. The first satellite, ERTS-1 (see Figure 1) was successfully launched in July 1972, and as a result of its success, a second satellite was launched in January 1975. At that time the program was renamed LANDSAT and the satellites became known as Landsat-1 and Landsat-2. The satellites are similar, having been patterned on the Nimbus meterological satellites which have an extremely precise, stable, attitude control and which have been in use since 1964. Both Landsat satellites carry the same sensors.

The satellites have been launched into near polar circular orbit at an altitude of 900km. The orbit is sun synchronous so that, apart from seasonal variations, the sun's angle of illumination of the area viewed by the satellite remains constant. Each orbit takes about 103 minutes, there being 14 revolutions of the earth each day. Successive orbits are separated by 25.8 degrees of longitude (see Figure 2) so that after 18 days the whole earth has been viewed once and repetitive coverage commences. Landsat-2 has been placed in orbit so that it follows Landsat-1 nine days later.

Satellite Payloads

In addition to a data collection sub-system used to collect and relay data from remotely located ground platforms to Landsat data acquisition stations, the payload of the satellites consists of a return beam vidicon sub-system (RBV) and a multispectral scanner sub-system (MSS); see Figures 3 and 4. These provide independent images of the same 185 by 185 km area of the earth in various spectral bands.

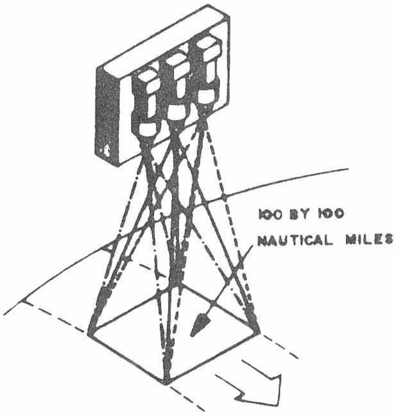

FIGURE 3

M(6)180

Principles of LANDSAT Return Beam Vidicon
(after Perry, 1972)

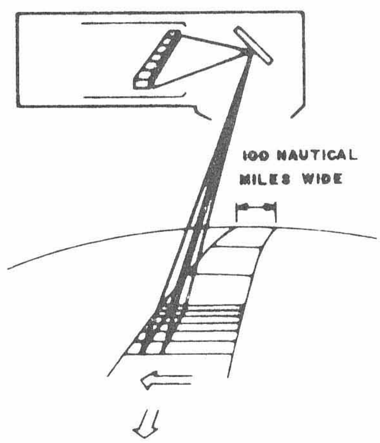

FIGURE 4

M(6)181

Principles of LANDSAT Multispectral Scanner
(after Perry, 1972)

The RBV sub-system contains three cameras, filtered to record the green (approx. 500-600nm), red (approx. 600-700nm) and infra-red (approx. 700-800nm) bands respectively. When shuttered, the cameras store images on photo-sensitive surfaces within each vidicon camera tube. The tubes are then scanned to produce video outputs requiring about 3.5 seconds to read out each of the three images in sequence. The cameras are reshuttered every 25 seconds to produce consecutive images along the satellite ground path overlapping by approximately 20%.

The MSS sub-system collects data in four spectral bands, three of which relate to the RBV cameras plus an additional infra-red band (800-1100nm) by continually scanning a swathe of the same width as the RBV cameras. Scanning is achieved through a mechanically oscillating mirror that flips from side to side about 13 times per second. During subsequent ground processing the continuous scan is formatted into images equivalent in area to those of the RBV cameras. According to pre-launch expectations, the MSS would have superior radiometric sensitivity, but inferior resolution and geometric accuracy, than the RBV sub-system.

The satellites carry on board tape recorders which can store the sensor information for subsequent relay to ground receiving stations; direct transmission of data can only be achieved as the satellite passes within radio range of the ground receiving stations.

Data Acquisition

There are three United States tracking and data acquisition stations, at Fairbanks, Alaska; at Goldstone, California; and at Greenbelt, Maryland. In addition Canada has an acquisition station at Prince Albert, Saskatchewan with processing facilities in Ottawa, which were used for Landsat-1 as well as Landsat-2; a second Canadian receiving station is also planned. Brazil installed a receiving station at Cuiaba for Landsat-2 with processing being carried out near Sao Paula; further receiving stations are being acquired by Italy, Iran, Zaire and Chile.

Data from the U.S. acquisition stations is sent to the NASA Data Processing Facility (NDPF) at Goddard Space Flight Centre where some 1300 scenes can be processed each week. Copies of all processed information are forwarded to the Department of Interior's Earth Resources Observation Systems (EROS) Data Centre at Sioux Falls, South Dakota, where they can be purchased by the public for the cost of reproduction.

Intially, the three RBV images of each scene (Bands 1, 2 and 3) and the four MSS images (Bands 4, 5, 6 and 7) are reproduced separately on 70mm film at a scale of 1:3,369,000. An enlargement of these onto 24cm film gives a scale of 1:1,000,000 which is most commonly used for interpretation and colour composite reproduction. In addition, many of the images can be ordered on magnetic tape in computer compatible form and these may be purchased for computer analysis of the imagery.

The next satellite in the Landsat series is due to be launched in September 1977; it will feature a more advanced RBV system with a proposed 40m resolution capability. Each RBV frame will cover only a quarter of the area covered by a single frame in the existing devices. This satellite, Landsat-C, will also carry an additional, infra-red, channel in the multispectral scanner.

Photography retrieved from the manned SKYLAB missions has also been evaluated for mapping purposes but it does not appear to have been employed for any mapping programs to date. Sensors on the planned SEASAT series satellites will be oriented towards oceanographic applications but they are not likely to be of cartographic value.

Activities in Australia

In June 1970 NASA sought proposals from interested scientific organisations for participation in the Landsat-1 experiment and as a result of the response from the Australian scientific community a Commonwealth interdepartmental co-ordinating committee called the Australian Committee for Earth Resources Technololgy and Science (ACERTS), was formed and prepared a set of Australian proposals. These proposals were multi-disciplinary and were designed to evaluate the usefulness of Landsat data and compare it with "ground truth" information available to the investigators. In all, some 48 reports of investigations were incorporated in a final report to NASA in March 1975 and included results of studies by Commonwealth and State Authorities, Universities and private companies in the fields of forestry, agriculture and land use, geography, geology, hydrology, cartography and interpretation techniques.

As the data acquisition stations for NASA sponsored imagery are located in North America, all Australian imagery was recorded on board the satellite and read-out during passes over the stations. This total reliance on the recorders limited the amount of imagery NASA was prepared to obtain and as those allocated to the RBV imagery on board Landsat-1 gave trouble very early in the mission, only a few RBV scenes were received. Although Landsat-1, with an original life expectancy of one year, is still operational, the tape recorders have been inoperative since mid-1974 and only real time acquisition of data is now possible.

The Division of National Mapping was involved in the Landsat-1 investigations primarily in the reproduction of imagery from NASA and its distribution to the Australian investigators. At the same time, the Division carried out its own investigations in relation to topographic, bathymetric and land use mapping. The quality of imagery received from NASA for the investigations was generally rather poor, which limited its usefulness to topographic map products. Considerable use has also been made of Antarctic imagery to produce mosiacs of rock and ice areas hitherto unmapped due to lack of photography and photogrammetric control

The quality of imagery received from NASA in the Landsat-2 program has generally been much better than that received from Landsat-1. However, only limited imagery has been received owing to the short period during which NASA took imagery over the investigation areas and owing to poor weather conditions prevailing during that period. Generally, the 24 cm image products received from NASA have better definition and resolution than the 70mm products.

APPLICATION OF LANDSAT IMAGERY TO OFF-SHORE MAPPING

With Landsat-2, NASA restricted the foreign investigations so that only five Australian investigators were selected to participate in the future studies afforded by the new imagery. In the event much of the Australian investigation has been thwarted by lack of suitable imagery. NASA ceased providing recorded imagery in December 1975. Included in the Australian investigations into Landsat-2 was a proposal by the Division of National Mapping to examine more fully the application of satellite imagery to the mapping of reefs and shoals around Australia.

The study has been aimed at examining the extent to which Landsat imagery could be applied to the Division's bathymetric mapping program. The idea for the investigation stems from a recognition that, although the Landsat satellite series is oriented towards monitoring earth resources and not towards accurate offshore mapping, the imagery does nevertheless quite accurately depict features such as islands and reefs and even shoal waters.

The Division's bathymetric mapping program is aimed at mapping the Australian continental shelf area to a depth of 300 metres at a mapping scale of 1:250,000. Furthermore, the major portion of this area has yet to be mapped in the program; much of the area contains islands, reefs and other features which should be discernible on the satellite imagery. Even though hydrographic charts cover some of these areas, the extent of the charts, their age and their accuracy is variable and not always satisfactory to the program's requirements.

Mapping from satellite imagery can be expected to have some advantages over conventional hydrographic survey techniques, for the following reasons:

(a) delineating reefs and islands and mapping in shallow water by conventional ship-borne techniques can be dangerous, slow, difficult, sometimes impossible, and in comparison to Landsat imagery, probably much more expensive; and

(b) because each Landsat image covers such a large area it could have valuable application in cases where aerial photographs cannot bridge expanses of featureless ocean.

From this background, then, the Landsat imagery was considered to be worth some investigatory effort. The work was also stimulated by some overseas success in determining water depths using satellite imagery.

Although the investigation may appear to duplicate work being undertaken elsewhere (including some work in Australia) on the cartographic application of this imagery, it is considered that the problems and solutions encountered in offshore mapping with the satellite products are not the same as those encountered in the mapping of on-shore, topographcial features. Offshore imagery characteristics include:

i) a lack of relief displacement;
ii) a lack of cultural features which may assist in identification;
iii) expanses of open water which do not need to be maped;
iv) inaccessibility, so that control stations often do not exist and are difficult to place;
v) limited options for control configuration; and
vi) the existence of tides which can alter the apparent shape and size of islands and reefs.

Landsat-1 imagery has already been used to revise reef and island positions and shapes on a series of maps of the Great Barrier Reef (known as the "Reconnaissance Series") which was largely uncontrolled and which received only very limited circulation. Figure 5 illustrates one area both before and after revisions were made using uncontrolled Landsat imagery magnified to a scale of 1:250,000. Figure 6 illustrates the complete coverage of the Barrier reef by the Reconnaissance Series and depicts the revision which was undertaken with the aid of Landsat-1 imagery.

Geometric Accuracy of the Imagery

A complete mapping technique which uses Landsat imagery is now being developed. However, it has been found in quantitative tests that the geometric accuracy of the multi-spectral scanner imagery approaches requirements for 1:250,000 scale mapping. The basic method of determining the planimetric accuracy of the MSS imagery has been to compare, via mathematical transformations, a set of image coordinates for a number of points on the image with the Australian Map Grid coordinates of the corresponding points on the ground. The transformation relationships correspond to the systems which would project the original control points onto the Landsat image, the residuals after least-squares comparison of the two sets of coordinates indicate the remnant distortions.

A number of different techniques have been used in this study:

i) the imagery used has varied from diapositives at 1:1,000,000 scale to paper prints at 1:250,000 and 1:1,000,000 scale to a display derived from a digital source;
ii) both conventional survey control points and identifiable map points have been used as control;
iii) various mathematical transformations — Helmert, Affine, Second Order Conformal and Bilinear— have been used to relate the sets of coordinates;

iv) a coordinatograph was used to measure the image coordinates and on one test digital methods were used to obtain image coordinates referred to scan-line numbers and picture-element numbers.

Results of tests which have been underaken on two scenes are shown on Table 1. They can be compared with the National Mapping Council specification which requires that 90% of tested points have an error less than 0.5mm, i.e. 125m at a scale of 1:250,000. For example, the results of Test 2b suggest that if the Landsat-2 scene 2125-01091 were corrected according to a Second Order Conformal transformation, 90% of tested points should have a position error not exceeding 295m. The earliest tests had deficiencies in the identification and measurement of control point coordinates and hence the magnitudes of residuals are greater than on later tests.

Satellite Bathymetry

The examination of the abstraction of water depths from the MSS imagery has not been conclusive. The Landsat-2 scene 1026-00035, of Torres Strait, which is shown in Figure 7 illustrates the different water penetration abilities of the four MSS bands.

Examples of successful and unsuccessful correlation between water depths and MSS band 4 image intensity values are shown in Figure 8. These cross sections were extracted by digital processes from magnetic tape forms of the Landsat-1 scene 1097-00054, which covers the South Australian Gulfs region; the intensity values are those abstracted directly from the digital form of the image. Water depths were obtained in this case from hydrographic charts. This investigation will continue on more advanced lines; in particular, the comparison between water depths and image values will be digitised.

The combined application of satellite bathymetry with an airborne laser depth profiling system is also being planned. This laser device has been developed by the Department of Defence Weapons Research Establishment for the Royal Australian Navy to a stage where trials will be undertaken in South Australia in late 1976. The water depths in which both the laser profiler and satellite scanner can be utilised are likely to be similar. In the ultimate configuration, the water penetrating laser could provide depth control profiles between which depth information can be interpolated using satellite imagery.

Without the laser profiler's assistance, the biggest obstacle to be overcome would be the difficulty of distinguishing between discoloured and shallow water. Nevertheless, it does seem that judicious use of the imagery can provide qualitative, if not quantitative, information on the existence and nature of shallow water areas.

CONCLUSIONS

Although conclusions have not yet been reached regarding the accuracy with which depths can be measured with Landsat imagery, some recommended procedures for the use of Landsat imagery for planimetric mapping are being prepared. It is proposed that some planimetrically accurate prototype maps depicting above water and shallow water features in offshore areas will soon be prepared from Landsat-2 imagery.

Any system which is capable of portraying scenes of areas on earth with any degree of accuracy must be expected to be applied eventually to mapping in some way. Landsat imagery has so far showed that it can contribute significantly to offshore mapping. A basic requirement for continued application of imagery, however, is the provision of facilities within Australia for real time acquisition of the data, a matter which is currently being considered by the Commonwealth Government. As satellite coverage increases and as instrumentation advances, the impact of satellite imagery in some fields of mapping could be revolutionary in the same manner that aerial photography has affected topographical mapping.

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