ISPRS Congress, Kyoto 1988. Commission IV

Information Content of High Resolution Satellite Imagery

I.J. Dowman and G. Peacegood

Department of Photogrammetry and Surveying,
University College London,
Gower Street,
London WC1E 6BT
UK.

ABSTRACT

A programme of work has been carried out at University College London with support from other mapping organisations in the UK to determine the amount of information which can be extracted from TM and SPOT in comparison with a variety of map scales, and in a variety of different types of area. Detailed plots from multispectral, panchromatic and stereo imagery have been compiled, and compared with available map data. The results from these experiments are presented.

1 Introduction

High resolution data is now freely available from the thematic mapper (TM) on Landsat and from SPOT. Attractive products have been shown which appear to show many features of the surface of the earth. There is however scepticism that these images can be used to satisfy the requirements of map makers and to replace the traditional methods of photogrammetry and land survey. Such sceptisism is often justified if satellite image products are compared to topographic maps produced by the rigorous methods and to specifications designed for such methods.

A programme of work has been carried out at University College London with support from other mapping organisations in the UK to determine the amount of information which can be extracted from TM and SPOT in comparison with a variety of map scales, and to relate the results to suitable specifications. To this end, detailed plots from multispectral, panchromatic and stereo panchromatic imagery have been compiled; and maps have been revised by comparing recent imagery to old maps. Some of the detailed plots involved 'blind' tests, while some were 'informed' (i.e., plotting was undertaken with reference to a map source, in order to get a measure of the absolute information content of the SPOT imagery)

In this paper we present the results of four tests in particular. The first, from Manosque in Southern France, attempts to relate information plotted from Stereo SPOT data with IGN 1:50,000 and 1:100,000 maps. The second, in S. Yorkshire and Nottingham shire in the United kingdom attempts to relate an 'informed' plot with recent OS 1:25,000 maps, and to identify change at 1:25,000 occurring between old and new maps. The third test, also in S. Yorkshire aimed to compare 1:50,000 maps with 'blind' plots made from SPOT XS and TM multispectral imagery. The final test was similar to the third, but for an undermapped area in Tanzania. The data available is shown in table 1.

Table 1. Test areas and data

Area	Size	Characteristics	Data
Manosque France	13km^2	Mixed Urban and Rural	Spot Pan, Stereo 18/5/86 (west 22.6^o) 1/6/86 (East -17.5^o)
South Yorkshire, Nottinghamshire, UK	10km ^{2} 20km^2	Mixed urban/rural	Spot pan, stereo 24/4/87 (West 17.5^o) 17/4/87 (East 18.4^o) Spot XS 15/6/86 TM 26/4/84
Korogwe, Tanzania	20km^2	Tropical/Rural	Spot XS 16/6/86 Spot Pan (mono)16/6/86 TM 12/3/84

It was originally intended that stereoscopic SPOT data would be used for all areas but SPOT Image have been unable to obtain stereo images of the Tanzanian area and the data which was obtained was imaged using the twin mode of XS and PAN together which has caused striping. The Tanzanian imagery was of poorer quality than that from UK or France, the data from the SPOT satellite being striped, and the data from LANDSAT being covered with scattered cloud throughout.

The first two areas exhibit very little relief, and a developed infrastructure of communications and settlement serving mainly agricultural commumuties. The third area is agricultural with poorly developed communications and terrain heights varying from 200 to 3500 m. The higher areas are forested. Good, recent mapping exists for the European areas at 1:50,000 and 1:25,000 scale. For the Tanzania area, 1957 maps and 1984 photogrammetric plots were available. The maps and ground control were provided by Ordnance Survey and by IGN (France) for the French area.

2. Image Processing

Data of all areas was provided in digital form and in some cases hard copy was also provided although this was not satisfactory in all cases. When using film products for topographic mapping, it is vital that high frequency linear detail in the imagery is preserved. The quality of the photographic imagery supplied by IGN being considerably degraded when compared to the original digital imagery. This imagery was rewritten using a McDonald Detwiller Fire 240 film recorder, which was found to be adequate for mapping purposes, but still did not contain as much information as the digital data.

Mapping was carried out from the multispectral data using hard copy enhanced on an I2S system and printed on a MDA Fire image printer. Of course there are numerous possible techniques for enhancing and preparing multispectral data for hardcopy, but of particular interest are the standard natural and false colour composites (FCC) which facilitate interpretation, and selection of optimal bands for the purpose of maximising the information content in terms of cultural features (a problem which is compounded by the fact that data sets from different sensors and satellites can easily be combined). .Table 2 shows the hard copy which was produced at 1:50,000 from the multispectral data sets. In general there was no attempt to merge bands from separate satellites, because one of the objectives was to compare the SPOT data with the TM data. For some of the hard copy a band selection algorithm originally proposed by Sheffield (1985) was applied to bands convolved with a high frequency edge filter, in order to optimise the selection process over band combinations with high (uncorrelated) edge frequency. (This of assumes that variations in edge frequency are related to cultural detail). A traditional FCC was not produced from the TM data of Tanzania because it was found that the high vegetation response in band 4 had a tendancy to mask the cultural detail.

Table 2 . Hard copy produced at 1:50,000.

Area	Sensor	Selection	Reasons
Tanzania	TM	3 2 1	Ease of interpretation Most common choice for image maps
		5 3 2	Popular combination Water body discrimination
		7 4 3	Chosen by band selection algorithm Incorporates 2 TM bands not yet used
	SPOT	Traditional FCC	
	Merged TM & SPOT pan	TM bands 3 2 1 SPOT pan	Increase detail of TM
S. Yorks	TM	5 4 1	Chosen by band selection algorithm
	SPOT	Natural colour*	Easier Interpretation
		Standard FCC	

*Produced by Hunting Technical Services Ltd

3. Plotting

Rigorous restitution was used for the stereoscopic SPOT images on the Kern DSR1 with SPOT software (Gugan and Dowman 1987). The Manosque stereo pair were also set up on the I2S photogrammetric stereoscopic image processing system (Gugan and Dowman, 1986). Digital data sets were prepared from all these sources. The results of the absolute orientations are shown in table 3. It is clear that the planimetric accuracy is suitable for 1:50,000 mapping.

Table 3 Accuracy of stereo model

Model	No of control points	No of check points	RMS X (check) m	RMS Y (check) m	RMS Z (check) m
S. Yorks	10	17	5.5	7.1	7.7
Manosque	10	58	15.9	11.3	5.4

A Digital data set was also prepared from monoscopic panchromatic SPOT imagery over Tanzania using a locally developed (Meneguette, 1987) monoplotter/ comparator. Analogue plots were prepared from SPOT XS and TM hardcopy imagery of Tanzania and S. Yorks, reproduced at 1:50,000.

Some work was also carried out into methods of map revision by superimposing a digital map onto the image displayed on the screen of a VAX station II GPX, areas of change on 1972 1:25,000 map data being detected in this way and the map then updated either on the DSR1, or on the GPX workstation itself.

The advantages of these various methods depend on the task in hand. The SPOT software is the obvious choice for map compilation given stereo pairs. The I2S offers the advantage over the Kern DSR 1 that digital imagery can be used in the map compilation, and that the quality of digital imagery is often higher than the quality of film written imagery. For map revision, it becomes necessary to be able to view the map and imagery simultaneously and preferably to superimpose the map data on the imagery whilst identifying the change (although not necessarily while plotting it) and the Laser-Scan software package Rover (monoscopic) was found to be a suitable tool for this task. For plotting the change the same software can be used, provided that the image can be registered to sufficient accuracy with the map (i.e., given a DEM for sideways looking SPOT imagery), or the DSR1 can be used. The digital mono plotting package developed at UCL produces ground/ map coordinates from image data which has not been resampled and hence there is an improvement in the image quality over images which have been registered to a map projection and/or filmwritten at a specific scale and projection. In addition, all the digital map compilation methods offer the advantage that the data can be plotted at any scale/ map projection. The hardcopy method of map compilation is generally faster, but there are disadvantages in that the imagery has gone through several processing stages, multiple enhancements are not possible (other than in the form of multiple hardcopys), and the map data can only be compiled at one scale. Stereo imagery often presents an aid to interpretation, but for revision purposes the ability to project the map to be revised onto the imagery is essential, at least for change detection, and preferably for plotting. When stereo data is unavailable, a digital plotting capability is still desireable.

The map sheets produced contain all the information which could be identified which falls within the Ordnance Survey 1:25,000 and 1:50,000 map specifications.

4. Evaluation

The map sheets that were produced as a result of the plotting stage were assessed by making a comparison with existing map sheets. Blind tests were made in the cases of Tanzania and S. Yorks multispectral data, and the Manosque stereo panchromatic data whereas 'Informed' tests (i.e, with reference to a map sheet) were made in the S. Yorks stereo data. In the former case, misclassification (in terms of errors of omission and commission, and between classes) is therefore of relevance, whereas in the latter case it is not, and a simple statement of the amount of detail for a given feature by comparison with the amount of detail shown on the map is adequate. Evaluation was generally performed by comparing the map length/ area of features, with the plotted length/area. In the case of urban development, areas of < 100 m squared were regarded as isolated settlements.

Most of the tests were done in comparison with 1:50,000 maps, with the exception of the plotting and revision exercises from panchromatic SPOT imagery of S. Yorks, which was in comparison with 1:25,000 maps.

5. Results

In this section, for the sake of brevity, only the main results of each test are presented. Figures such as the absolute length/ area of the feature extracted are not given, although where relevant some additional comments are given.

5.1. Test 1 - Manosque

The errors arising out of the SPOT plot of the Manosque area, by comparison with 1:50,000 and 1:100,000 maps, are summarised in table 4

Table 4 Detail correetly plotted in Manosque information content test

Feature	% plotted correctly (correctly plotted detail less commission)
Roads (Major)	87
Canals (Major)	100
Rivers	100
Railways	97
Residential buildings	67
Industrial buildings	(many changes which could not be checked)
Minor roads/tracks	24
Canals (Minor)	0
Streams	55

5.2. Test 2 - S. Yorks, sheet 745/ SK68/ SK78

5.2.1. Information content in SK 78.

The results of the tests concerned with information content in S. Yorks are summarised in table 5. The first column refers to the length of features detected in the plot, as compared with the length of features depicted in the 1987 map. The second column refers to the amount of change which had occurred between the previous map edition (1980) and 1987, and which had been picked up in the plot.

Table 5. Features extracted from stereo SPOT compared with OS 1:25,000 sheet 745/ SK78

Stereo S Yorks (SK 78) 1:25,000	% features extracted	% change detected post 1980
All Roads/tracks	67.5	39.34
Roads > 4 m wide	88.8	100
Roads < 4m wide	64.1	no change
Tracks	49.9	24.5
Railway	72.4	no change
Isolated settlement < 100 m^2	56.7	40.79
Settlement area > 100 m^2	81.8	77.38
Field boundarys/Land plots	57.3	unrepresented in old maps
Canals/Rivers/Streams	55.86	no change
Reservoirs	48.33	48.33

Reservoirs accounted for only three features, one of which was detected. The other two (as confirmed in the field) were represented by scrub islands intersperced with brackish water, at the sites of old quarrys. Having established the nature of these features in the field, it is possible to identify them in the SPOT imagery. Some specific comments can be made about the nature of those isolated settlements which are easily visible in SPOT panchromatic data. They tend to be farms which often include a metal roofed building. The small tracks which were missed often hugged field boundarys or were hidden in forested areas.

5.2.2. Revision in SK 68

For the revision exercise, The SPOT imagery was used to identify and plot change from1972 1:25,000 maps, and then compare that change with 1987 1:25,000 maps. Table 6 summarises the results of this exercise. Positive change implies features that are represented in the most recent (1987) map, but were not in the old (1972) map, whereas negative change implies features that were represented in the old map, but are not in the new one

Table 6 - Change detected in panchromatic SPOT by comparison with OS 1:25,000 sheet 745/ SK68

	positive change %	negative change %
Tracks	30.2	41.2
Isolated Settlement < 100 m squared	23	12.5
Settlement area > 100 m squared	84.7	no change
Reservoirs/Gravel Pits/quarrys	61.3	95.5
Airfield	no change	100

100% indicates all change detected.

The 100% correctly identified change at the airfield represents only 1 feature, but the nature of the change was quite complex, with parts of the airstrip remaining (and recognised as such from SPOT), and parts now gone. Negative change in the isolated settlements class accounts for only one feature out of eight. The comments made above regarding reservoirs hold true in the change detection experiment as well. As for positive change around the urban fringe, figures are certainly better than is suggested by the results, because at least two modern housing estates which were detected in the revision exercise were confirmed in the field, but postdated the most recent map of the area.

5.3. Test 3 - S. Yorks, Sheet 111 (Multispectral SPOT and TM imagery)

For this test, two extra quantities were established: absolute omission (percent detail in a particular class which had not been plotted in any category), and absolute commission (percent detail which had been plotted in a particular class and did not belong in any category). These measures effectively provide a measure of the information that can be extracted, even if it is not classified correctly. Table 7 summarise the errors found in the information extraction experiment by comparison with the OS 1:50,000 sheet 111

Table 7 Errors in plot of OS sheet 111 from TM and SPOT XS

	Road		Motorway		Railway		Track	
	TM	SPOT	TM	SPOT	TM	SPOT	TM	SPOT
	%	%	%	%	%	%	%	%
Omission	48	38	17	0	36	48	90	80
Absolute omission	46	33	0	0	32	35	77	59
Commission	30	29	0	0	2	0	72	67
Absolute commission	20	15	0	0	2	0	51	48

The higher resolution SPOT XS data gave better results for the detection of the smaller linear features, roads and tracks. Furthermore, the overall length of these features was much greater than the length of motorways or railways. Misclassification between classes is summarised in tables 8 and 9.

Table 8 Breakdown of misclassification in TM/ SPOT

		Plotted interpretation (%)				
		Road	Motorway	Railway	Track	Total
correct	Road	58/58	0/0	0/0	3/4	61/62
interpretation	Motorway	1/0	7/7	0/0	0/0	8/7
(%)	Railway	2/3	0/0	19/13	0/0	21/16
	Track	6/8	0/0	0/0	4/7	10/15
	Total	67/69	7/7	19/13	7/11	100

KEY TM/SPOT

5.4. Test 4 - Tanzania.

The results of this test are of dubious reliability due to a number of factors, including image quality, nature of the ground truth, cloud cover and lack of operator experience in the area under investigation. The main results of this test are summarised in table 9.

Table 9. Errors of commission amd omission in 1:50,000 monoscopic plots of Tanzania in comparison with 1957 map data (cultural features only)

	Road %	Rail %	Track %	Road/track/rail %
TM 321	28/31	50/48	90/90	59/59
TM 532	38 /51	54/51	88/78	59/48
TM 643	34/46	48/51	83/74	60/50
SPOT XS	51/46	47/47	97/88	75/47

KEY OMISSION/COMMISSION

Comparing the information in the photogrammetric plot with the information in the map showed just how different the two data sets were. Fifty percent of the detail in the road/track/rail class that had been present in the 1957 map was not present in the photogrammetric plot, and twenty two percent of the detail present in the photogrammetric plot was not present in the old map. Neither of these information sources were considered to be very reliable. Table 10 gives some results obtained by comparing the image plots with the 1984 photogrammetric plots

Table 10. Errors of commission and omission in TM 321 and Spot panchromatic (monoscopic) plots derived from comaprison with 1983 photogrammetric plot data.

	Road/track/rail	
	Omission	Commission
TM 321	37	33
SPOT Panchromatic	37	17

This area was comparatively lacking in complexity in terms of density of cultural detail (for the SPOT data, the map length of roads in Tanzania was 97234 m, and the plot length was 87788 m, whereas in the UK (test 3) the map length was 553402 m and the plot length was 482600 m). Generally, about 10 percent of the error in omission could be accounted for as the class misclassification in the Tanzanian imagery between roads/tracks and roads/railways, and likewise about 17 percent of the commission error, and these figures were fairly consistent across the different plots in Tanzania.

A note of comparison between the Tanzania and the UK multispectral data studies: Comparing the most general information extraction levels (ie, no misclassification, all cultural classes) gives results of 38% omission and 19% commission for the SPOT data over the UK, as compared with 37% omission and 33% commission for the TM 321 data over Tanzania (by comparison with the photogrammetric plot). In Tanzania, omission was improved by 10% on average by ignoring the effects of misclassification, and commission by 17%. In the UK, omission for SPOT was improved by 9% and commission by 12%. Settlements and roads/tracks were much more difficult to detect in the Tanzania imagery than in the European areas, and (Image quality considerations apart) this probably reflects the natural building materials more widely used in this area.

6 Map Specifications

It is clear from the work carried out at UCL and from published work that an image map can be constructed relatively easily and can be of great use to local organizations. It is also apparent that the use of SPOT panchromatic data gives a significantly higher level of reliability and the use of stereoscopic plotting ensures that errors due to relief are not significant. Furthermore costs of producing image maps, without reliable and accurate overlays of cultural information are relatively low. From these conclusions it is possible to derive guidelines and production flow lines for various stages of map production. When considering whether the use of satellite data is appropriate for use in a mapping project it is necessary to consider the purpose of the map, the time scale in which the map is required and the availability of existing data.

Two extreme scenarios illustrate the factors to be considered:-

a) If topographic line maps are required to a conventional specification, adequate funding is available and it is possible to obtain aerial photography, then the use of satellite data is probably inappropriate.

b) If maps are required quickly, within a limited budget and a relaxed specification is acceptable then there is probably a very good case for using satellite data.

Between these two extremes a range of possibilities exist. Other factors to be considered are:

a) Availability of existing maps and survey information for control and completion.

b) Weather conditions in tropical areas, if no data exists allow at least one year for data to be acquired.

Product specification should depend on product use rather than on historical convention. A hierarchy of products can be set out which ranges from a line map through an image map with added detail in vector form to an image map which is geometrically corrected with administrative information added (names etc), a grid, title and border information. The advantages and disadvantages of these products can be summarised as follows:

Advantages	Disadvantages
IMAGE MAP	
Simple and quick to produce	Missing information
Gives immediate impression of character of land area (eg wooded, urban, field pattern) and of landforms	Information subject to misinterpretation
	Quality subject to available imagery which may have defects or cloud cover
Shows many features such as field patterns, landforms, tracks not on line map	
Does not need a detailed specification as content is defined by imagery	
IMAGE WITH DETAIL OVERLAY	
As for image map plus: More complete information	Needs to satisfy a specification to ensure reliability, therefore needs field completion
	Possible confusion with too much information (image and line)
LINE MAP	
Clear and easily understood	Expensive and time consuming to produce
Reliable and accurate (if up to date)	Needs to satisfy specification and if reduced specification then problems with educating user

The most important feature of most conventional map specifications for 1:50,000 mapping is that information should be complete and accurately positioned. It has been demonstrated that satellite data can be used to give accurate positioning but that the information will not be complete and, without ground checks, may be subject to misinterpretation. The extent of ground completion and ground verification is likely to be greater than that expected when aerial photographs are used (given the same specification) and therefore has a clear bearing on the cost of a mapping project. The decision boundaries between features of similar type need perhaps not be made in the same way as it is with maps - for example, between villages represented as solid areas and groups of isolated houses represented separately, or between minor roads, tracks and footpaths. Nonetheless, the problem cannot be completely overcome by producing a new specification for maps produced from satellite data because it is unlikely that a map which specifies that the road network is not complete will be acceptable to users. Education can play an important part in map acceptance, but there must be minimum requirements. Published information suggests that an image map is a useful product, particularly in areas where no up to date mapping exists. A primary question is therefore: what is the correct balance between cost and completeness? A secondary question is: Which areas are most suited to use of such a product? It is suggested that a suitable specification for an image map at 1:50,000 scale would contain the following features:-

a) The image should be geometrically rectified to satisfy a normal 1:50,000 specification

b) The image should be enhanced to show to the best advantage features of the landscape such as landforms and vegetation cover.

c) An overlay of detail should include primary settlements, significant isolated buildings, communications, water features, power lines, pipelines and other significant features necessary for orientation.

d) An overlay of names and administrative features should include names of towns and natural features, administrative boundaries and a grid

[The overlay features would closely correspond to a 1:250 000 specification]

Information concerning the third dimension in the form of spot heights or contours could be added if available.

It would be necessary to carry out field completion and verification, and to use any available information such as other satellite imagery, aerial photographs and existing maps to satisfy such a specification but the costs should be significantly less than mapping at 1:50,000 scale and the product useful in poorly mapped areas

7. Conclusions

Overall, the results of the evaluations tended to indicate that 1:25,000 mapping objectives are probably over ambitious for stereo SPOT data, and likewise 1:50,000 mapping is over ambitious for mapping from multispectral SPOT and TM data. However, this over-specification of the problem was a deliberate attempt to find out "how far" these types of imagery can go. Any specification which requires the depiction of isolated settlements or small tracks are unlikely to be met by SPOT panchromatic data, let alone the other sources, but on the other hand a majority of urban areas, railways, major roads and areal features can be detected. Motorways are generally 100% visible in all types of imagery. Most major roads and railways are also visible, but railways can be more difficult to detect eg. where they are single track, and in complicated sidings, etc. Part of the explanation for is probably due to the spectral reflectance properties of railways as against asphalt. Minor roads and tracks are more difficult to detect, and can often be missed in the lower resolution imagery, or where they follow field boundarys or are occluded by wooded areas. Areal features such as urban boundarys, reservoirs, or quarries can generally be detected with ease, as long as they exceed 100 m^2. Where these features are missed, field work is likely to reveal an explanation.Isolated settlements are generally invisible in 20 and 30 m data. In 10 m data many isolated settlements remain invisible. Those that are visible are often farm complexes with metal roofed (eg corrugated iron) buildings.

Change detection of small tracks and isolated settlements (which account for a large proportion of the change in 1:25,000 maps) are nearly impossible to detect in SPOT panchromatic imagery with any degree of reliability. On the other hand, change in urban extent, or other areal developments, such as quarries and reservoirs, can generally be detected reliably. Although there had been very little change in the road network in the area under investigation during the timescales involved, such changes as there were could be detected easily.

Acknowledgements

The authors would like to acknowledge the support of the Ordnance Survey for tests 2 - 4, of Laserscan Laboratories for the use of the ROVER package on the VAX Station II GPX and the help of D. Gugan for some of the results concerning model accuracy.

References

Gugan D J and Dowman I J, 1986, 'Design and Implementation of a digital Photogrammetric System', *International Archives of Photogrammetry and Remote Sensing,* 26(2):100 - 109.

Gugan D J and Dowman I J, 1987, 'Accuracy and Completeness of Topographic Mapping from SPOT data', *Presented at: Joint meeting of the Photogrammetric Society and the Remote Sensing Society, London, November 1987*

Meneguette AAC, 1987, 'Cartographic Accuracy and Information Content of Space Imagery for Digital Map Compilation', *Phd Thesis, University of London.*

Sheffield C, 1985, 'Selecting Band Combinations from Multispectral Data, *Photogrammetric Engineering and Remote Seneing,* 51(6), 681 - 687.