



European Organization for Experimental Photogrammetric Research

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Oeepe-Project on Topographic Mapping from High Resolution Space Sensors

by David Holland, Bob Guilford
and Keith Murray

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Table of contents

<i>D. Holland, B. Guilford and Keith Murray: Oeepe – Project on Topographic Mapping from High Resolution Space Sensors</i>	9
Index of figures	10
Index of tables	12
Summary	13
Acknowledgements	14
Layout of this report	14
1 Introduction	14
1.1 Aim of the project	14
1.2 Work packages	15
1.3 Participants	15
2 Test sites and test data	16
2.1 Specification of the test data	17
2.2 Additional data	18
3 Summaries of the Reports	
3.1 Work Package 1 - Topographic mapping from high resolution space sensors .	19
3.1.1 Objectives	19
3.1.2 A summary of the Work Package 1 report by Paul Marshall, Ordnance Survey United Kingdom	19
3.1.3 A summary of the Work Package 1 report by Anders Ryden, National Land Survey of Sweden	20
3.1.4 A summary of the Work Package 1 report by Karsten Jacobsen, University of Hannover	21
3.2 Work Package 2 - DEM generation	22
3.2.1 Objectives	22
3.3 Work Package 3 - Automatic change detection	22
3.3.1 Objectives	22
3.3.2 A summary of the Work Package 3 report by Peter Atkinson and Isabel Sargent, University of Southampton	22
3.4 Work Package 4 - Automatic land use classification	23
3.4.1 Objectives	23
3.4.2 A summary of the Work Package 4 report by Peter Atkinson and Isabel Sargent, University of Southampton	24
3.4.3 A summary of the Work Package 4 report by Peter Lohmann et al, University of Hannover	24
3.4.4 A summary of the Work Package 4 report by Bulent Cetinkaya et al, General Command Of Mapping, Turkey	25
3.5 Work Package 5 – Software	25

4	Implications and key issues	25
4.1	Data availability and data quality	25
4.2	Costs	26
4.3	Speed of developments	26
4.4	Challenges to existing products.....	27
4.5	Satellite imagery vs aerial imagery	27
4.6	Opportunities.....	27
5	Conclusions	27
5.1	Work package 1 – Topographic Mapping.....	27
5.2	Work package 2 – DEM Creation	28
5.3	Work package 3 – Change Detection.....	28
5.4	Work package 4 – Land Use	28
5.5	Work package 5 – Software	28
5.6	General Conclusions	28
6	Recommendations	29
	Annexe 1: High Resolution Sensor data for topographic mapping, <i>Paul Marshall</i> , Ordnance Survey United Kingdom	31
	Annexe 2: Topographic Mapping from High Resolution Space Sensors, <i>Anders Ryden</i> , National Land Survey of Sweden	53
	Annexe 3: Geometric Aspects Of IKONOS Images, <i>Karsten Jacobsen</i> , University of Hannover	61
	Annexe 4: High Resolution Sensor data for Automatic Change Detection, <i>Peter M.</i> <i>Atkinson and Isabel M.J Sargent</i> , University of Southampton	71
	Annexe 5: High Resolution Sensor data for Automatic Land Use Classification, <i>Peter</i> <i>M. Atkinson and Isabel M.J Sargent</i> , University of Southampton	91
	Annexe 6: Land Cover Classification using High Resolution IKONOS Data, <i>Peter</i> <i>Lohmann et al</i> , University of Hannover	105
	Annexe 7: Evaluating The Classification Results Of IKONOS Multispectral Satellite Imagery In The Production Of Landcover Map, <i>Bulent Cetinkaya et al</i> , General Command Of Mapping, Turkey	135
	Reference	153

Oeepe – Project
on
Topographic Mapping from High Resolution Space Sensors
Report editors: David Holland, Bob Guilford and Keith Murray, Ordnance Survey
Topographic Mapping from High Resolution Space Sensors

Index of Figures

Annexe 1

Figure 1	Area 1. Rural / urban subset area of IKONOS image	34
Figure 2	Area 2. Mountainous area of IKONOS image	34
Figure 3	IKONOS image of the urban test area	37
Figure 4	Aerial photograph of the urban test area	37
Figure 5	Surveyed buildings plotted from a 2nd order polynomial geo-correction of the valley area of Area 2	43
Figure 6	Flow diagram of a typical photogrammetric map revision flowline	45
Figure 7	Base map extracted from Area 1. of the IKONOS image	49
Figure 8	Imagemap extracted from Area 1. of the IKONOS image	49

Annexe 2

Figure 1	The figure shows two sub-scenes for built-up areas, represented by the two different band combinations. The approximate scale is 1:10 000	55
Figure 2	The figure shows two sub-scenes for evaluation of the road network, represented by the two different band combinations. The approximate scale is 1:10 000	56
Figure 3	The figure shows two sub-scenes for evaluation of land use and vegetation, represented by the two different band combinations. The approximate scale is 1:10 000	57
Figure 4	The figure shows two sub-scenes for evaluation of the drainage network, represented by the two different band combinations. The approximate scale is 1:10 000	58

Annexe 3

Figure 1	Original geometric relation of satellite line scanner images	65
Figure 2	Different view directions possible from IKONOS	65
Figure 3	Geometry of CARTERRA Geo	66
Figure 4	Geometric displacement of an object located above the plane for rectification	66
Figure 5	DEM of the test area in Switzerland	67
Figure 6	Geometric differences CARTERRA Geo against control points	68
Figure 7	Differences after correction by the influence of height	68
Figure 8	Differences after correction by influence of height + shift in X and Y	69
Figure 9	Differences after correcting the influence of height + similarity transformation to control points	69

Annexe 4

Figure 1	OS simulated DNF data showing altered features as follows	77
Figure 2	IKONOS MS imagery of Fair Oak, Eastleigh, Hampshire	78
Figure 3	(a) k-means classification of the IKONOS MS image, (b) Adaptive Bayesian classification of the IKONOS MS image (class 1 is woodland, class 2 is grassland and class 3 is built land)	79
Figure 4	Local binary difference between (a) the k-means classification and the unique identifier data and (b) the adaptive Bayesian classification and the unique identifier data	80

Figure 5	Local binary difference between (a) the k-means classification and the Type data and (b) the adaptive Bayesian classification and the Type data .	81
Figure 6	Local (thematic) variance predicted for (a) the unique identifier data and (b) the Type data	82
Figure 7	Local (thematic) variance predicted for (a) the k-means classification and (b) the adaptive Bayesian classification	83
Figure 8	Local difference between the local variances of (a) the k-means classification and the unique identifier data and (b) the adaptive Bayesian classification and the unique identifier data	84
Figure 9	Local difference between the local variances of (a) the k-means classification and the Type data and (b) the adaptive Bayesian classification and the Type data	86
Annexe 5		
Figure 1	(a) Per-pixel classification of land cover made using the IKONOS MS sub-image of Chandler's Ford; (b) the equivalent per-parcel classification of land cover based on the per-parcel mode in (a)	101
Figure 2	Per-parcel classification of land cover in IKONOS MS sub-image of Chandler's Ford obtained by applying the per-parcel classifier to the per-parcel average spectral values in each waveband of the imagery	101
Figure 3	(a) Per-pixel classification of land cover made using the IKONOS MS sub-image of Chandler's Ford, together with a Local Variance 'waveband'; (b) the equivalent per-parcel classification of land cover based on the per-parcel mode in (a)	102
Figure 4	(a) Per-pixel classification of land cover made using the IKONOS MS sub-image of Chandler's Ford, together with a Local Variance 'waveband' and the NDVI 'waveband'; (b) the equivalent per-parcel classification of land cover based on the per-parcel mode in (a)	103
Annexe 6		
Presentation		106
Annexe 7		
Figure 1	Signature Mean Plot of the Unsupervised Classification	137
Figure 2	Signature Mean Plot of the Unsupervised Classification	139
Image 1a	IKONOS Multispectral Satellite Image (4 metre)	140
Image 1b	Unsupervised Classified Image (six classes)	141
Image 1c	Supervised Classified Image (eight classes)	142
Image 1d	Supervised Classified Image after neighbourhood filtering (3x3)	143
Image 1e	Supervised Classified Image after neighbourhood filtering (5x5)	144
Image 1f	Landmap (Ordnance Survey 10K raster) of the area of interest	145
Image 2a	IKONOS Multispectral Satellite Image (4 metre)	146
Image 2b	Unsupervised Classified Image (six classes)	147
Image 2c	Supervised Classified Image (eight classes)	148
Image 2d	Supervised Classified Image after neighbourhood filtering (3x3)	149
Image 2e	Supervised Classified Image after neighbourhood filtering (5x5)	150
Image 2f	Landmap (Ordnance Survey 10K raster) of the area of interest	151

Index of Tables

Main report

Table 1	Project participants	16
Table 2	Metadata supplied with the imagery	17

Annexe 1

Table 1	Summary of the findings of capturing all feature codes for this trial	36
Table 2	Product accuracy offered by Space Imaging. Note: CE90 is the circular accuracy with a confidence level of 90%	40
Table 3	Accuracy of results comparing raster map, aerial photography and Area 1 (rural), 2nd order polynomial geo-corrected IKONOS image (all figures in metres)	42
Table 4	Accuracy of results comparing raster map, aerial photography and Area 2 (mountain), 2nd order polynomial geo-corrected IKONOS image (all figures in metres)	42
Table 5	Flowline costs	46
Table 6	The basic products offered by Space Imaging (in 2001). These prices are per square kilometre. A minimum order of \$1000 for USA and \$2000 for International orders is required	47

Annexe 2

Table 1	The table gives a summary of the major findings of the evaluation of the IKONOS multi-spectral data for the Swedish 1:10 000-scale map	59
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Annexe 3

Table 1	original pixel size on ground [m] depending upon view direction	62
Table 2	spectral range of IKONOS images [μm]	63
Table 3	IKONOS- (CARTERRA-) products with accuracies claimed by Space Imaging	64

Annexe 5

Table 1 (a)	Relation of CORINE classes to DNF data and IKONOS MS imagery	98
Table 1 (b)	Relation of CORINE classes to DNF data and IKONOS MS imagery	99

Summary

The aim of this project was to investigate the potential for national mapping organizations to utilise high-resolution satellite imagery. Several different topics were to be covered by the research, including the production and update of topographic mapping; the creation of Digital Elevation Models; the automatic detection of change; the automatic classification of land-use; and the evaluation of image processing software. In practice, the work on Digital Elevation Models was not covered in this research, due to the unavailability of suitable stereo imagery. Each of the topics was covered by a different Work Package, and each Work Package was undertaken by one or more organizations.

OEEPE members have shown an interest in high-resolution satellite imagery for several years, an interest which was confirmed at a meeting in March 1998. It was decided that an evaluation project should proceed in May of that year, using imagery from forthcoming satellite sensors. At that stage, a number of national mapping organizations and universities across Europe were each prepared to carry out an assessment using their own methods and against their own national mapping specifications. In the event, it would take over a year for the first successful launch of a high-resolution satellite – Space Imaging's IKONOS in September 1999.

After some initial delays in obtaining suitable imagery, IKONOS data from two test sites was acquired from Space Imaging. This imagery, from Chandlers Ford (UK) and Lucerne (Switzerland), was distributed to the participants at the end of March 2001. Topographic map data from these areas was also obtained, from the national mapping organizations, and distributed to the participants. The long lead-time of this project caused several of the original participants to withdraw, but by the end of the project there were four complete reports available, plus five others - either interim reports for the May 2001 OEEPE Science Committee or other submissions.

It is evident from the research that high-resolution satellite imagery does make it possible to detect certain topographic features such as buildings and roads. It offers potential for mapping organizations to reduce costs and increase efficiency; but in order to realise this potential the availability of the imagery will need to be improved, the cost of imagery must come down, and the mapping specification will need to be modified. However, it is expected that high-resolution satellite imagery will not totally replace traditional imaging technologies but will be utilised alongside them. An exception to this could be in developing countries which are poorly mapped at the moment, where space imagery could provide maps more quickly than conventional methods (given favourable cloud conditions).

The utilisation of high-resolution imagery for cadastral and large-scale topographic map update is some time off, but the market continues to develop, and with it the need to keep abreast of developments. For example, towards the end of this OEEPE project DigitalGlobe successfully launched their QuickBird satellite, which at the time of writing (June 2002) is now capturing and supplying large amounts of high resolution imagery.

The availability of high-resolution imagery challenges the basis of conventional map products. Future customers may prefer an image backdrop with combinations of vector overlays for points of interest, non-topographic information and transport networks.

In addition to the support of existing products, the potential for generating new products for as yet undefined markets gives mapping organizations the opportunity to form partnerships with organizations in the high resolution satellite imagery industry.

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Peter M. Atkinson and Isabel M.J. Sargent	University of Southampton
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Layout of this report

This document is collated from the reports of each of the OEEPE members who undertook one or more of the work packages. The main body of the report sums up the findings of each work package and presents conclusions and recommendations. The reports of the each of the project participants are included as separate annexes.

1 Introduction

1.1 Aim of the project

The aim of the project, as stated in the original OEEPE Project Proposal, was to investigate the potential for deriving products from high resolution space imagery. The advent of high-resolution sensors has potential application in the fields of geographic information, topographic mapping, height modelling, change detection and land classification. Many OEEPE members have direct interest in evaluating the benefits of this data; a fact confirmed in a preliminary meeting held in March 1998. In May 1998 the OEEPE Steering Committee approved the instigation of an evaluation project and the planning for practical work began in June of that year.

The first commercial high resolution sensor to become operational - Space Imaging's IKONOS satellite - was launched successfully in September 1999. The high demand for imagery from this satellite meant that access to suitable high-resolution data for this project was not achieved until December 2000. Test data (imagery of the UK and Switzerland) was supplied to OEEPE members at the end of March 2001.

1.2 Work packages

OEEPE members expressed interest in various different aspects of high resolution satellite data, so the project was split into several work packages and each organization chose to undertake one or more of these.

At the start of the project, the work packages were defined as follows:

- Work Package 1:** Evaluate the practicality of using High Resolution Sensor Data for topographic mapping
- Work Package 2:** Evaluate the practicality of using High Resolution Sensor Data for DEM creation and update (accuracy of 1 metre and above)
- Work Package 3:** Evaluate the practicality of using High Resolution Sensor Data for automatically detecting topographic change in urban and rural areas.
- Work Package 4:** Evaluate the practicality of using High Resolution Sensor Data for automatic classification of land use (emphasis on rural areas)
- Work Package 5:** Investigate the maturity of software systems products to exploit imagery from High Resolution Sensor Data.

Rather than treat the software systems as a separate work package, it was decided to incorporate this into the other work packages.

During the first year of operation, IKONOS monoscopic imagery was in great demand, and the overheads of collecting in stereo meant that Space Imaging collected very little stereo imagery during the period of this project. Although several attempts were made to acquire stereo imagery during the course of the project, these were unsuccessful and, regrettably, work package 2 had to be abandoned.

1.3 Participants

below details the participants and their interest at the time when High Resolution Sensor Data became available:

Table 1: Project participants

Contact Name	Agency/Company	Country	Work Packages			
			W P1	W P2	W P3	W P4
Fred Bishop	Ordnance Survey	UK	✓		✓	✓
Peter Atkinson	Southampton University	UK			✓	✓
Ian Dowman	University College London	UK	✓	✓	✓	
Robert Wright	University of Aberdeen	UK				
David Miller	Macaulay Land Use Institute	UK		✓	✓	✓
Stephen Wise	University of Sheffield	UK		✓		
Bulent Cetinkaya	General Command of Mapping – Turkey	Turkey	✓	✓	✓	
Wolfgang Foerstner	University of Bonn	Germany	✓	✓	✓	
Olaf Hellwich	Technical University Munich	Germany				
Christian Heipke	University of Hannover	Germany	✓		✓	
Juha Jaakola	Finnish Geodetic Institute	Finland	✓	✓	✓	✓
Juha Vilhomaa	National Land Survey of Finland	Finland	✓	✓		
Lars Tyge Jorgensen	National Survey and Cadastre – Denmark	Denmark		✓	✓	
Martin Roggli	Federal Office of Topography – Switzerland	Switzerland				
Lars Savmarker	National Land Survey of Sweden	Sweden	✓			✓

2 Test sites and test data

It was proposed that OEEPE would purchase IKONOS imagery specifically for this project, and that the imagery should represent each of the following land cover types:

- Urban and Rural
- Mountainous and Flat
- Forested areas and open areas

An initial request for candidate test sites resulted in the following shortlist:

- Belgium – North West Gent, Flanders, North West Belgium
- Finland – Ivalo, North Finland
- Germany – Bremen, North Germany
- Switzerland – South Lucerne, Unter Walden central Switzerland
- UK – St Albans

Participants were invited to state their preferences in April 2000, and the Bremen site was chosen. Bremen imagery was ordered in September 2000, but had not arrived by January 2001. Once the data was obtained, it was then discovered that it had an unacceptable amount of cloud cover.

To enable the work to commence, it was decided that the project would not procure new imagery but would instead use existing data of Lucerne and Chandlers Ford, donated to the project by OEEPE members.

The two test site areas covered different land cover types: mountainous landscape for Lucerne in Switzerland and urban and rural areas for Chandlers Ford in the UK.

2.1 Specification of the test data

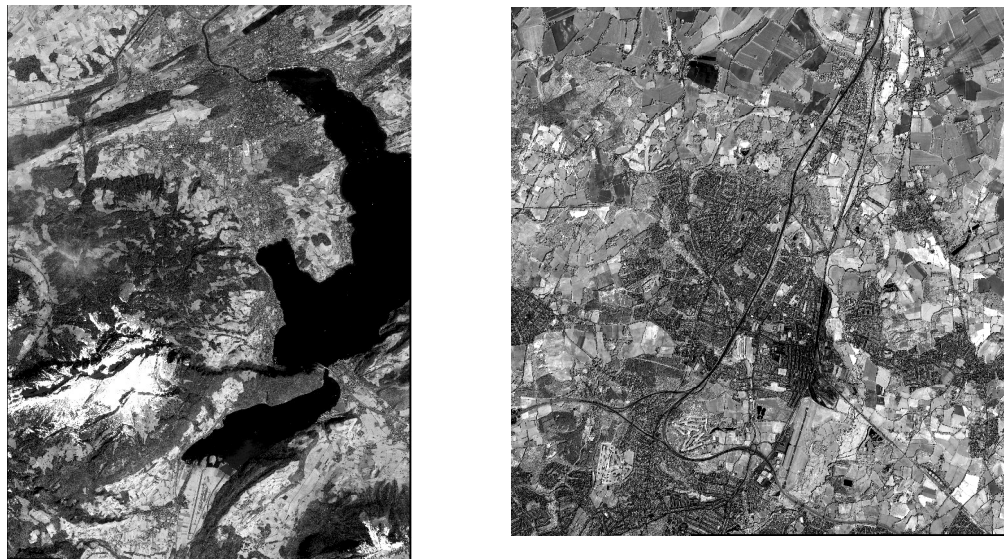
Both the images used in the test were IKONOS “GEO” products, geometrically corrected with a nominal accuracy of 50m (Circular error, 90% confidence). The metadata for the two images is reproduced in Table 2. Further details of the geometric and radiometric characteristics of the images can be found in Annexe 3.

Table 2: Metadata supplied with the imagery:

	Lucerne data	Chandlers Ford data
Image type	Panchromatic	Multispectral
Pixel size	1m	4m
Processing level	Standard Geometrically Corrected	Standard Geometrically Corrected
Accuracy	50 metres	50 metres
Map Projection	UTM zone 32 N	UTM zone 30 N
Datum	WGS 84	WGS 84
File format	GeoTIFF (tiled) – 11 bits per pixel	GeoTIFF (tiled) – 11 bits per pixel
Spectral range	0.45 to 0.90 microns	-
Acquired Nominal GSD	cross scan – 0.95m along scan – 0.89m	cross scan – 1.13m along scan – 0.97m
Nominal collection azimuth	256 degrees	255.3 degrees
Nominal collection elevation	67°	49°
Sun angle azimuth	153°	162°
File format	GeoTIFF	GeoTIFF
Area	183 km ²	129 km ²
Date of acquisition	22/04/2000	25/08/2000

Image extent	Geographic coordinates on WGS84 spheroid			
	Latitude	Longitude	Latitude	Longitude
Coordinate: 1	47.07438534°	8.21116872°	50.93396424°	-1.45014450°
Coordinate: 2	47.07531542°	8.36030226°	51.03589304°	-1.44674600°
Coordinate: 3	46.92940961°	8.36204155°	51.03362555°	-1.28464059°
Coordinate: 4	46.92848423°	8.21331341°	50.93170493°	-1.28839337°

Overview images of the test sites, Lucerne (left) and Chandlers Ford (right).



Images copyright © SpaceImaging

2.2 *Additional data*

In addition to the IKONOS imagery, various other datasets were provided to the participants to enable them to perform qualitative and quantitative tests on their results. These datasets included:

- LandPlan raster (1:10 000 scale) of Chandlers Ford, from Ordnance Survey
- Large scale polygon data of Chandlers Ford from Ordnance Survey (referred to in the Annexes as Digital National Framework, or DNF based data. The commercial product based on DNF is now known as OS MasterMap).
- Habitat (land use and land cover) data for Chandlers Ford from Hampshire County Council
- Pixel maps (1:25 000 scale) of Lucerne from the Swiss Federal Office of Topography
- Digital orthophotography for Lucerne from the Swiss Federal Office of Topography

A set of guidelines on the assessment criteria to be used for each of the work packages was also sent to each of the participants.

3 Summaries of the reports

The number of final reports received was less than originally expected, principally due to the delay in obtaining imagery, which caused several participating organizations to reallocate resources to other work. However, several of the organizations did provide interim reports or other material during the course of the project. It was decided that any communications received during the project – interim reports, final reports or presentations – would be considered for publication, and where possible these have been included in the Annexes.

3.1 *Work Package 1: Topographic mapping from high resolution space sensors*

3.1.1 Objectives

This first work package set out determine whether the satellite imagery of the test sites could be successfully used as the source material for the update of conventional topographic mapping, using the mapping specifications of the researchers involved. The formal objectives of the work package were as follows:

- To survey the topographic features in a defined area, and assign feature codes according to each participant's specification and requirements.
- To assess the positional accuracy of the newly surveyed features, along with the identification and interpretation accuracy. The accuracy of using High Resolution Sensor data will be compared with conventional survey methods (aerial photography).
- Assess the costs and benefit of using High Resolution Sensor data over conventional survey methods (aerial photography).
- Investigate the maturity of software system products used to complete the topographic mapping

Three reports were submitted for this work package, from Ordnance Survey Great Britain, National Land Survey of Sweden, and the University of Hanover, Germany.

3.1.2 **A summary of the Work Package 1 report by Paul Marshall, Ordnance Survey, United Kingdom (Annexe 1).**

This report evaluates the panchromatic imagery of the Lucerne site. Although the Chandlers Ford site would seem to be more fitting to the national mapping organization of Great Britain, the 4m multispectral imagery available for Chandlers Ford was deemed to be inappropriate for the mapping scales used in Great Britain (i.e. 1:1250, 1:2500 and 1:10 000 scales).

The evaluation of the Lucerne data demonstrated that high resolution space imagery suffers from the same problems as digital mono panchromatic aerial photography – such as those caused by height displacement and cloud cover and that of feature interpretation in dense urban areas. Interpretation of the imagery would have been improved by stereo coverage – which would have also enabled the derivation of DTMs – and by pan-sharpened imagery, in which the identification of features may be aided by their colours. Multispectral imagery would also allow greater discrimination between vegetation, buildings and shadows, especially in urban areas.

The main drawback of the 1m imagery was the difficulty in interpreting fences and other small linear features. Such features are an integral part of many current spatial data and mapping specifications, and without these features the specifications cannot be satisfied.

The smallest scale to which this applies varies from country to country, depending on the national and local specifications, but would typically be between 1:10 000 and 1:25 000. There are two ways in which this imagery could be used for revision of mapping at larger scales - change the map specification or change the requirement of which features will be revised (i.e. only major topographic features)

IKONOS imagery was found to be a viable alternative to aerial photography for checking the currency of mapping. This was helped greatly by the ease of ortho-rectification and the large area coverage provided by satellite imagery.

During the course of the research, IKONOS imagery suffered from limited availability and uncompetitive pricing when compared with typical aerial photograph available in the UK. Since the project was completed, DigitalGlobe have successfully launched the QuickBird satellite, which provides sub-metre resolution imagery and brings some competition into the market. This has already led to lower prices and greater availability of high-resolution imagery. In the first year of operation of the IKONOS satellite, Space Imaging's policy appeared to favour government and military organizations. Civilian and commercial users were given lower priority or were refused access to data (eg the stereo imagery, which was initially only available to government customers). Space Imaging ascribe these early restrictions to the overwhelming demand for data during the first year, and now say that data is much more readily available.

The report concludes that IKONOS imagery has potential for topographic mapping. This is particularly so in developing countries and remote areas, where topographic mapping/revision from traditional photogrammetric methods can be expensive and impractical.

3.1.3 A Summary of the Work Package 1 report by Anders Ryden, National Land Survey of Sweden (Annexe 2)

The National Land Survey of Sweden reports on the evaluation of the IKONOS 4m multi-spectral imagery of the Chandlers Ford site against the specification for the Swedish digital database, which is also used for the Swedish 1:10 000-scale map. Four different topographical themes were used for the evaluation; built-up areas, communication, land use & vegetation, and drainage. Two different band combinations were evaluated; one resembling a normal colour photograph, and one resembling an infrared photograph. The evaluation was carried out manually, on-screen. Results for the four different themes are summarized below:

Built-up areas - These are easy to identify and delineate and, based on context and pattern, it is possible to differentiate between residential and industrial/commercial areas. Other prominent features, such as cemeteries and recreation areas, are equally easy to identify. For these and for detection of point features, the IKONOS imagery is suitable for use in the updating of mapping at the 1:10 000 specification.

Large buildings are easily detected in the images. However, the resolution is not high enough to enable identification and outline of details such as small houses, although it is possible to mark these features as point objects.

Communication - For line features, such as roads and railways, the IKONOS multi-spectral imagery is suitable for the update of the Swedish 1:10 000-scale map. Distinguishing between smaller features such as tracks and footpaths, tree-lined fences, hedges and ditches is not easy and may be heavily dependent upon the context and the contrast of the surroundings.

Major point features such as railway stations are also possible to detect and identify. Other point features (e.g. communication masts) can be detected but not reliably identified.

Land use and vegetation - For land use and vegetation the IKONOS imagery is suitable for delineation and identification of all the features as specified for the Swedish 1:10 000-scale map. The infrared band combination is the easiest image to interpret and, when applied in forested areas, reveals several different reddish tones indicating the ability to distinguish between different tree types and compositions as well as indicating clear cut areas.

Drainage - The infrared band combination is again somewhat better for detection and identification as open water has a black, easily distinguishable signature in the image. For rivers and streams, this imagery is suitable for updating of the Swedish 1:10 000-scale map. It is likely to be possible to detect and identify some point features, such as major waterfalls and rapids. Minor man made structures represented as point objects in the map may be possible to detect but not necessarily to identify.

A definite advantage with the IKONOS data is the availability of several bands allowing the image to be displayed in different combinations. This allows the viewer/interpreter to select the band combination that best suits the purpose of the application. As compared to lower resolution satellite data, the IKONOS data also provides the interpreter with an extra indicator not common in satellite data interpretation, i.e. the shadow.

The conclusion is that the imagery is suitable to use for the update of most features in the map as stated in the Swedish 1:10 000 specification. Although it has not been possible to evaluate the geometric accuracy of the image during this work, it should in theory be good enough for revision of the database

3.1.4 A summary of the Work Package 1 report by Karsten Jacobsen, University of Hannover (Annexe 3)

This report describes the geometric and radiometric properties of IKONOS images, and considers the fact that Space Imaging only market processed IKONOS satellite imagery, rather than the original raw line-scanner images. The cheapest, and therefore most widely used, IKONOS product is CARTERRA Geo – a rectification to a horizontal surface – which has a stated horizontal accuracy of 50metres. The report explains how the geometry of CARTERRA Geo-products can be upgraded to an accuracy corresponding to the CARTERRA Precision Plus product, without knowledge of the full scene orientation

The rectification process uses an approximation based on the known satellite orbit, the nominal elevation and azimuth information (taken from the image metadata), a digital terrain model, and a small set of control points. From these, the scene orientation was approximated, using software developed at the University of Hannover. This information was then used within another Hannover program to orthorectify the image. The resulting orthoimage was found to have a horizontal accuracy of 2m (RMSE).

The report concludes that, given a set of control points, a DEM, and the nominal elevation and azimuth angles of the image, the CARTERRA Geo product can be rectified to a level of accuracy which is theoretically sufficient for mapping at scales of between 1:10 000 and 1:20 000.

3.2 *Work Package 2: DEM generation*

3.2.1 Objectives

The second work package required a stereo pair of IKONOS images in order to create a digital elevation model (DEM) of the test site. The objectives of this work package were defined as:

- Create DEMs automatically from the High Resolution Satellite data using image correlation.
- Assess the accuracy of the automatically created DEMs.
- Assess the potential of using High Resolution Sensor data for building modelling.
- Cost benefit analysis to be applied to all above project objectives.
- Investigate the maturity of automatic DEM creation software system products to exploit imagery from High Resolution Sensor data.

Unfortunately it was not possible to obtain stereo imagery for either of the two test sites. Following further interest shown at the OEEPE meeting in May 2001, a renewed attempt was made to purchase stereo imagery. Nigel Press Associates (an IKONOS imagery distributor in the UK) was approached for stereo coverage. An area in Belgium was chosen but, on closer examination of the stereo archive, it was found that the images had 70% cloud cover and were therefore not suitable. There was then insufficient time left within this project to repeat the process, hence no stereo imagery was acquired.

For that reason, no work was carried out on work package 2.

3.3 *Work Package 3: Automatic change detection*

3.3.1 Objectives

This work package sought to determine whether high resolution satellite imagery could be used to support the automatic detection of features which had changed between two points in time. In practice, this involved an analysis of change between map data from one epoch, and imagery from a later epoch. The formal objectives of the work package were defined as:

- Identify change in the given test site using available algorithms
- Assess the accuracy of the change detection algorithm.
- Carry out a cost benefit analysis of using satellite imagery verses aerial photography
- Investigate the maturity of software system products to exploit change detection from High Resolution Sensor data.

Only one report was received on this subject, perhaps suggesting that automatic change detection is a research area which has yet to reach maturity; or that a comparison between a map and an image is not the best method of change detection.

3.3.2 **A summary of the Work Package 3 report by Peter Atkinson and Isabel Sargent, University of Southampton (Annexe 4)**

This report was written by Southampton University on behalf of and sponsored by the Ordnance Survey of Great Britain.

This aim of the study was to compare IKONOS imagery with OS MasterMap vector data, to determine whether changes to the topographic features could be automatically detected. The first observation to be made was that the best way to detect change would be to compare like with like (ie to compare two IKONOS images from different dates; or to compare two sets of vector data). Since this was not possible, given only one IKONOS image, an alternative approach was required. The approach adopted in this project was to classify both the IKONOS imagery and a rasterized version of the vector data. These raster datasets were then compared, using various local statistics techniques – specifically the “k-means” clustering algorithm and the Adaptive Bayesian Clustering (ABC) technique.

A number of synthetic “changes” were introduced into the vector data, to determine whether these could be detected using local statistics techniques. The results showed that, in the agricultural area of the image, the changes were correctly identified. However, the techniques also generated many false-alarms, due to several factors, including:

- Adjacent land-cover areas of the same type – which were shown as distinct fields within the vector data but which were of the same classification within the image.
- Scale of analysis – the 12m by 12m window used for local analysis of the data worked in rural areas, but was not suitable in urban areas where the size of individual features is of a similar size to this window.
- Misregistration of the image with respect to the vector data, especially in urban areas.
- Boundary features – fences and hedges recorded as lines within the vector data, but classified from the image as distinct objects with a definite area.
- Land cover classification problems in urban areas – caused by varying illumination and shadow conditions.

Issues arising included the need for accurate geometric rectification, the size of support window chosen and the lower success rate achieved in urban areas. The main conclusion was that it was possible to detect change in agricultural areas, but there were problems of a high false alarm rate. In urban areas various illumination conditions and shadows severely limited the ability to detect change.

The report recommended that like-with-like comparisons (IKONOS image to IKONOS image) should be the preferred method where possible to avoid the need for very careful pre-processing prior to change detection.

3.4 Work Package 4 - Automatic land use classification

3.4.1 Objectives

The goal of work package 4 was to determine whether high resolution satellite imagery could be automatically classified into land-use areas. The formal objectives were:

- To classify land use in a defined area using the CORINE specification.
- To evaluate the practicality of using High Resolution Sensor data to obtain information for automatic land use classification.
- To evaluate the achievable accuracy of using High Resolution Sensor data for automatic land use classification.

- To perform a cost benefit analysis of using High Resolution Sensor imagery versus conventional methods.
- To investigate the maturity of software system products to exploit automatic land use classification from High Resolution Sensor imagery.

Three submissions were received for Work Package 4 – one final report, one interim report and one slide presentation. Each of these is reproduced as an annexe.

3.4.2 A summary of the Work Package 4 report by Peter Atkinson and Isabel Sargent, University of Southampton (Annexe 5)

This report concentrated on the imagery of the Chandlers Ford area of the UK. It utilised structured large-scale polygon data (the forerunner of OS MasterMap) supplied by the Ordnance Survey. The objective was to classify the area to the CORINE specification. The study found that the OS MasterMap data is already classified to some extent and that a large proportion of CORINE classifications could be populated using the information already held in the large-scale polygon data at attribute level. Notwithstanding this conclusion, a classification of a small subset of the IKONOS imagery was performed, using a maximum likelihood classifier. Four classes were identified (woodland, smooth grass, rough grass and bare soil) and the image was classified on a per-pixel basis. The classified pixels were then analysed on a per-parcel basis; in which each OS MasterMap polygon was assigned the modal class of all the pixels it contained. In a separate experiment the mean spectral values within each polygon were used to perform a direct per-parcel classification. Interestingly, these two methods gave different results – especially when differentiating between rough and smooth grassland.

The report concludes that a combination of OS MasterMap data and IKONOS imagery could be used to identify most of the CORINE classes, with the possible exception of ‘mineral extraction sites’, ‘vineyards’ and ‘pastures’.

3.4.3 A summary of the work package 4 report by Peter Lohmann et al, University of Hannover - (Annexe 6)

This submission was in the form of a slide presentation, which is reproduced at Annexe 6. The study concentrated on the multispectral image of the Chandlers Ford area, using ERDAS Imagine and Definiens eCognition software. Use was made of the OS LandPlan 1:10 000 scale raster data and land use data provided by Hampshire County Council (although it was noted that this was not based on a CORINE classification). The high resolution of the imagery was found to introduce new aspects not normally found in multispectral satellite imagery. One of these is the presence of shadows in the image, which can be used to identify larger buildings and trees. A second aspect of the high resolution imagery is the heterogeneity of the image - each land parcel may be made up of several different classes, which would have been averaged out in lower resolution imagery. The use of the CORINE classification itself was found to be problematic, in that it caters for usage types of natural objects (e.g. “sport and leisure facilities”) rather than the land cover types (e.g. “grassland”) which can be determined from the imagery. This was especially the case in urban areas (Annexe 6.2).

The resolution of the imagery was not sufficient to differentiate buildings and streets within a housing area – it is suggested that the 1m panchromatic imagery would be useful for this. The report concluded that, while high resolution imagery has the potential to permit detailed classification, new techniques need to be developed to aid the classification process.

3.4.4 A summary of the Work Package 4 report by Bulent Cetinkaya et al, General Command Of Mapping, Turkey (Annexe 7)

This report was submitted in the first call for interim reports. Unsupervised classification was performed using the ISODATA algorithm and supervised classification utilised the maximum likelihood rule. The authors discuss the effects of different window sizes on the effectiveness of the classifications. Using six classes, the unsupervised classification gave satisfactory results, while the supervised classification performed well except for the classification of water. To cover all the water features in the image, three different water classifications had to be used.

As this was meant as an interim report, it deals with work-in-progress, and offers no formal conclusions. However, from the results presented it is clear that the IKONOS multispectral imagery can be used to classify land-cover to a level of accuracy satisfactory for the General Command of Mapping in Turkey.

3.5 Work package 5 - Software

As stated earlier, this work package was incorporated in the other four. No formal evaluation of software was performed by the participants in the project, but several points can be made from the reports submitted for the other work packages.

ERDAS Viewfinder was issued with the data to all participants. ERDAS Imagine was used by several of the project participants, and Definiens eCognition 1.0 and ERDAS Expert Classifier was used by the University of Hannover.

It has been noted by many researchers that Space Imaging do not release the sensor model parameters needed for ortho-rectification, which restricts the accuracy of the information that can be derived from the basic IKONOS imagery. This initially allowed Space Imaging exclusively to provide value-added products such as ortho-rectified imagery. Some software manufacturers, including PCI geomatics, ERDAS and Earth Resource Mapping, have provided tools which enable users to overcome this problem, using either the “Geo Ortho Kit” from Space Imaging, or by using proprietary techniques to derive an approximate sensor model from the image metadata. Details of this process may be found in Karsten Jacobsen’s report (Annexe 3) and in the work of Toutin and Cheng (2000) described in Annexe 1.

Peter Lohmann reported that eCognition software could be improved with the addition of vector handling (Annexe 6). The report by Paul Marshall of Ordnance Survey refers to the potential use of PCI Geomatics - Ortho Engine and other software to rectify IKONOS imagery.

4 Implications and key issues

4.1 Data availability and data quality

There were severe difficulties in obtaining suitable data and in particular it proved impossible to obtain stereo imagery in the timeframe of the project. Space Imaging now state that the initial problems of limited availability are now behind them, and that mono imagery data can be ordered, captured and supplied within a few weeks. However, evidence from several researchers indicates that stereo IKONOS imagery is still very difficult to obtain.

To facilitate the accurate detection and capture of features to meet the specifications for large-scale topographic mapping databases, IKONOS imagery must be ortho-rectified. This

requires access to a DTM, a set of ground control points and, ideally, the IKONOS sensor model. Since the full sensor model is unavailable, other means of rectifying the image must be used (see Annexe 1, section 3.2; and Annexe 3)

4.2 Costs

At the time of the research, the estimated purchase costs for this OEEPE project for a minimum order of 25 sq km were given as:

1m Pan: \$66 per sq.km

4m Multi-Spectral: \$66 per sq.km

1m Pan Sharpened Multi-Spectral (3 bands): \$88 per sq.km

1m Pan Sharpened Multi-Spectral (4 bands): \$106 per sq.km

Typical 0.25m aerial imagery: \$50 per sq. km - or less

The launch of more high resolution Earth observation satellites should increase competition for this type of imagery and drive costs down in the future. (Afternote: This has already started to happen with the launch of the QuickBird satellite. The above prices, though current at the time of the research, are no longer valid).

4.3 Speed of developments

This project suggests that the utilisation of high-resolution imagery for the update of cadastral and large-scale mapping is some time off, but the market continues to develop, and with it the need to keep abreast of developments. During the last two months of this OEEPE project two more high-resolution satellites have been launched. Although one of these, OrbView 4, failed to reach its intended orbit and is not operational, the other, QuickBird, was launched successfully and has already begun to collect imagery. The first imagery products from QuickBird were released to the market in early 2002. QuickBird takes the level of detail a step further than IKONOS, providing 0.61m panchromatic imagery and 2.4m multispectral imagery. Data of this resolution is of great interest to national mapping organizations, as it is getting close to the level of accuracy required for the update of their databases.

In addition to an increase in the number of satellites and in the resolution of imagery they capture, it is expected that new radar sensors and hyperspectral sensors will be launched. These will complement the imagery from panchromatic and multispectral sensors, enabling users to see more detail and derive more information from the images, especially in the determination of land cover.

In 2001 several highly-classified "Keyhole" satellites were launched by the US military. Although no information is available in the public domain regarding the image resolution possible from these satellites, it is widely speculated that they are capable of resolving objects as small as 10cm. Although interesting from a technology perspective, none of the data from this type of satellite will be declassified in the foreseeable future, if ever, especially in the light of the heightened security after the September 11th terrorist attacks.

As new satellites are developed and launched, OEEPE should continue to monitor their capabilities and periodically review the types of product available.

4.4 Challenges to existing products

The availability of high-resolution imagery challenges the basis of conventional map products. Future customers may prefer to use images in conjunction with simple vector datasets of transport networks, points of interest and other, non-topographic, information. This provides more flexibility than the digital databases derived from traditional, static, cartographic maps. Users will be able to combine imagery with exactly the type of vector product which satisfies their requirements, and such a composite product may provide more value than the traditional digital map. Even traditional map users will gain value from imagery, which will show detail - such as some street furniture and individual trees - not present in most mapping products. There is also the cultural factor to address – imagery in its many forms is such a familiar medium that some users will be more comfortable with an image than they are with a map. This familiarity can only be strengthened by such things as image servers on the internet and high-resolution “fly throughs” on ever-more-realistic computer games.

4.5 Satellite imagery vs aerial imagery

Pundits in the remote sensing and GIS industry expect the imagery market to continue to grow, and predict that satellite imagery will take up a greater proportion of the market than at present. As satellite imagery approaches the level of detail traditionally associated with aerial photography, it will begin to attract a greater range of users. Providers of aerial photography are likely to try to counteract this by collecting even higher-resolution data, ensuring a healthy imagery market for the foreseeable future.

Several researchers commented on the presence of shadows in the images, which are a feature of aerial photography but are not often found in satellite imagery of lower resolutions. It is interesting to note that the National Land Survey of Sweden (Annexe 2) and the University of Hannover (Annexe 6) found that the presence of shadows in this imagery was an aid to feature identification, while the University of Southampton (Annexe 4) found that “In urban areas various illumination conditions and shadow undermined the ability to detect change”.

4.6 Opportunities

It has been shown in this project that high resolution satellite imagery has the potential to support existing products of national mapping organizations. This potential will increase as new satellites are launched, leading to greater competition in the industry. This will almost certainly lead to a wider coverage of low-priced data, which can be more widely employed within the map production workflow. In addition, high resolution satellite imagery gives mapping organizations the opportunity to work with commercial partners to develop new products and to open up new markets.

5 Conclusions

The conclusions for each of the work packages are as follows:

5.1 Work package 1 – Topographic mapping

The imagery was useful for small and medium scales and to a variable degree for large scales data capture. The success rate depended on the rigidity and detail of the mapping

specification. For example, within Great Britain, physical land parcel boundaries are shown. These could not be reliably detected. In this example an option would be to re-evaluate the need to capture all boundary features. Greater success was reported in rural areas and for water features. In urban areas it was difficult to accurately distinguish building outlines.

5.2 Work package 2 – DEM creation

As noted previously, no work was carried out for this work package due to the unavailability of the necessary stereo imagery.

5.3 Work package 3 – Change detection

It was not possible to compare IKONOS images from different epochs for the same area. Therefore the images were compared against the vector or raster topographic data provided.

One finding was that as spatial resolution increases so too does the requirement for precision in the geometric rectification of the data. This requirement is likely to be greater in urban areas than in agricultural areas.

5.4 Work package 4 – Land use

An accuracy of 89% classification was achieved. Some low density classifications were lost within larger classifications. High resolution permits detailed classification but it also gives an increased heterogeneity within fields of the same land cover. Therefore class assignment becomes more difficult and the complexity of the model increases.

High resolution satellite data requires new techniques, which are not restricted to standard statistical multispectral approaches.

5.5 Work package 5 – Software

Several commercially available image processing software packages were used and were found to be capable of manipulating the IKONOS imagery. The lack of an IKONOS sensor model may cause some problems when orthorectifying the imagery, but these may be overcome using software and techniques described in this report.

5.6 General conclusions

The availability of high-resolution satellite imagery makes it possible to detect certain topographic features (see work package 1). Its use for capturing traditional large-scale topographic detail, particularly in urban areas, is limited although this may improve as the resolution of satellite imagery increases.

High resolution Space Sensors continue to offer potential for mapping organizations to reduce costs and increase efficiency. The technology will not replace other alternatives but will be utilised alongside them.

6 Recommendations

Mapping organizations need to look at the ways that high-resolution imagery can be used, not only in existing products but also in new innovative products. For example, customers may prefer image backdrops integrated with vector features to conventional mapping.

The subject of mapping from high resolution satellite data will remain a central research topic for the foreseeable future – it is recommended that OEEPE consider holding a regular forum, possibly in conjunction with ISPRS, to update the membership on developments in high-resolution imagery, backed up by a network of interested users and researchers.

Products from other high-resolution satellites should be investigated and compared to IKONOS products.

Follow on work should include the evaluation of stereo high-resolution imagery.

Index of Annexes

Annexe 1: High Resolution Sensor data for topographic mapping, *Paul Marshall*, Ordnance Survey United Kingdom

Annexe 2: Topographic Mapping from High Resolution Space Sensors, *Anders Ryden*, National Land Survey of Sweden

Annexe 3: Geometric Aspects Of IKONOS Images, *Karsten Jacobsen*, University of Hannover

Annexe 4: High Resolution Sensor data for Automatic Change Detection, *Peter M. Atkinson and Isabel M.J Sargent*, University of Southampton

Annexe 5: High Resolution Sensor data for Automatic Land Use Classification, *Peter M. Atkinson and Isabel M.J Sargent*, University of Southampton

Annexe 6: Land Cover Classification using High Resolution IKONOS Data, *Peter Lohmann et al*, University of Hannover

Annexe 7: Evaluating The Classification Results Of IKONOS Multispectral Satellite Imagery In The Production Of Landcover Map, *Bulent Cetinkaya et al*, General Command Of Mapping, Turkey

OEEPE – Project
Topographic Mapping from High Resolution Space Sensors
Report by Paul Marshall
Ordnance Survey United Kingdom
Work package 1 – ‘High Resolution Sensor Data for Topographic Mapping’

1 Introduction

1.1 Background

The advent of high resolution satellite sensor imagery has potential application in the fields of topographic mapping, height modelling, change detection and land classification. The members of OEEPE (European Organisation for Photogrammetric Research) have a direct interest in evaluating the benefits of this data. Ordnance Survey is leading a project which is seeking to evaluate the use of high resolution space sensors in all the aspects of mapping listed above, using IKONOS satellite imagery. The project is split into 5 work packages. This is a report into work package 1; an evaluation of the use of 'High Resolution Sensor Data for Topographic Mapping'.

1.2 Introduction to the project

IKONOS commercial satellite imagery is the highest resolution satellite imagery available to the public at the time of this project. The satellite was launched in September 1999 and is equipped with a Kodak-built pushbroom scanner, whose panchromatic sensor is equipped with a 13,500 pixel linear array with a 12mm pixel size, creating Panchromatic imagery of 1m ground sample distance (GSD). This resolution is the equivalent to that obtainable from 1:40,000 aerial photography (Petrie, 1998). Also captured by this satellite is 4m GSD multispectral imagery.

In the world today there is a growing demand for:

- a) up-to-date topographic mapping, be it brand new mapping or revision of existing mapping.
- b) digital orthoimagery (particularly high-resolution up-to-date imagery) as backdrop mapping in the Geographic Information Systems of local government and utility companies.

IKONOS imagery has huge potential to assist in both of the above disciplines. This is particularly so in remote areas of the world and in developing countries where conventional high-resolution digital aerial imagery is more difficult to obtain than in developed countries.

This work package has evaluated the use of this imagery in respect of the following aspects:

- 1 feature extraction
- 2 accuracy
- 3 cost
- 4 software / current situation

1.3 Objectives

The objectives of Work Package 1 were defined as follows:

- To survey the topographic features in a defined area, and assign feature codes according to each participant's specification and requirements.

- Assess the positional accuracy of the newly surveyed features, along with the identification accuracy. The accuracy of High Resolution Sensor data will be compared with conventional survey methods (aerial photography).
- Assess the cost benefit analysis of using High Resolution Sensor data over conventional methods (aerial photography).
- Investigate the maturity of software system products used to complete the topographic mapping

The evaluation for each section was based around the assessment criteria supplied with the data at the start of the project.

1.4 Description of data

For this trial a 1m-resolution panchromatic mono image of the Lucerne area of Switzerland was used. The image is the standard 'Geo Product' from Space Imaging, further details of which may be found in the main report and in Annexe 3.

In addition to the satellite image, a raster map (1:25 000 scale) and a set of aerial orthophotos (1:25 000 scale, 35cm pixel resolution) were provided by the Swiss Federal Office of Topography.

2 Surveying of topographic features

2.1 Objective

To survey the topographic features in a defined area, and assign feature codes according to each participant's specification and requirements.

2.2 Methodology.

Two subset areas were created to perform manual extraction of topographic features. Area 1 was low-lying and contained both rural and urban features (see Figure 1). Area 2 was in a more mountainous area containing mountain, forestry and rural features (see Figure 2).



Figure 1: Area 1. Rural / urban subset area of IKONOS image.

Area 1: 1m panchromatic area in Lucerne

1. Urban/Rural area.	NW corner	East	441700	North	5212500
	SE corner	East	444400	North	5209800

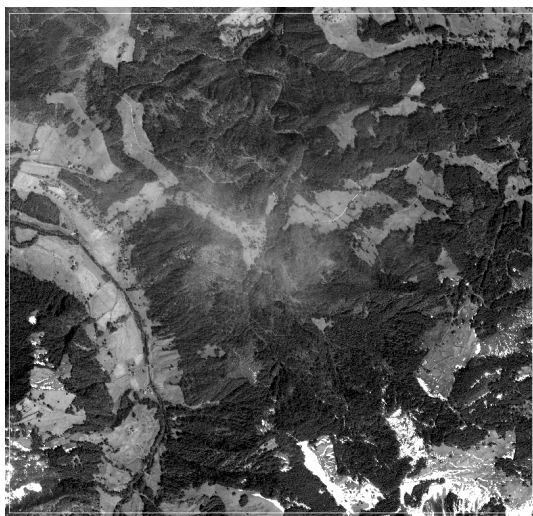


Figure 2 Area 2. Mountainous area of IKONOS image.

Mountainous / forested area	NW corner	East	440252	North	5207655
	SE corner	East	444085	North	5204001

To perform this trial it was necessary to have the raster map, aerial ortho-images and IKONOS images in a common map projection. Each data set was adjusted to the Swiss co-ordinate system (Reference System - CH1903 / Ellipsoid – Bessel 1841) using ERDAS Imagine software. Once these were established it was possible to overlay each set of data for comparison. It was also possible to load the imagery into L/H Systems SOCET SET and ERDAS Imagine. For feature extraction the Annotation functionality was used in ERDAS Imagine. This enabled each feature type to be captured in a separate layer, with the end product being a simple vector map, without detailed attributes. Note that, at the time of this project, it was not possible to orthorectify IKONOS imagery using standard software packages, since the characteristics of the IKONOS sensor were not publicly available. The image subsets were therefore warped to fit the map detail (as discussed below in section 3.3).

Within each subset, a manual survey of the area was performed, keeping to the Ordnance Survey data capture specification as far as possible. The resulting features were compared with the features on the 1:25 000 map, which was taken to be the true picture of the area.

2.3 Results.

Below is a summary of the results, compiled from the findings in each area. Errors of omission and commission are represented as follows: The second column indicates the percentage of “known” features on the map which were correctly identified in the imagery (e.g. 80% of the building outlines present in the map were correctly identified as buildings in the image). The third column indicates the percentage of features which were mis-identified in the image (e.g. 10% of the features captured from the image as buildings were not present as buildings in the map). This means that the two numbers relate to slightly different things and will not therefore add up to 100%.

Table 1: Summary of the findings of capturing all feature codes for this trial.

Feature	correctly identified	misidentified	Causes of error
Building outline	80%	10%	• Vegetation • Only general shape • Divisions difficult
Railway detail	80%	0%	• Unable to see each rail • Educated decision • Multiple rails difficult to separate
Roads (inc. m/ways)	90%	10%	• Tree cover • Kerbs and central reservations difficult
General line detail	30%	20%	• Fences too small • Large walls are clear • Boundaries generally difficult • Hedges OK
Paths	50%	20%	• Difficult to see in woods • Cut-off between tracks and paths difficult to distinguish
Tracks	80%	20%	• Quite clear
Vegetation	90%	10%	• Difficult to annotate • Good overview
Forestry	95%	5%	• Very clear • Difficult to assess tree type
Electric' poles	20%	0%	• Unable to see power lines • Very difficult to see poles
Water detail	80%	20%	• Tree cover a problem • Shallow water difficult to see
Rivers and streams	70%	20%	• Large rivers easy to detect • Small streams are very difficult to distinguish from paths

2.4 *Description of results* *Comments on each type of feature.*

2.4.1 **Buildings**

These were quite easy to detect and capture. However, it was difficult to correctly extract the geometry – only a general outline could be detected. Problems arose in the urban area when attempting to differentiate between outhouses, extensions or simply parts of the main building. In the city centre of Lucerne, stereo imagery would be required to confidently capture the buildings in their correct position. The image used in this survey suffers from overthrow effects caused by the 67° collection elevation angle of the satellite. This overthrow was discernible throughout the image and an experienced eye was required to correctly capture the position of the building line on the ground. Building divisions could only be determined by educated guesswork.

Experience of the digital monoplottting flowline at Ordnance Survey has shown that a mono image is not as good as a stereo image for capturing the detailed juts and recesses and divisions of housing.

This suggests that this form of image would only be suitable for capturing buildings for 1:10,000 or smaller-scale topographic mapping, where some generalisation takes place. However, in dense city-centre areas, it is likely that stereo imagery would be necessary for all building extraction.

To aid in the appreciation of the problems associated with this imagery, below is a comparison between the IKONOS image and the aerial ortho-images supplied for this trial. These are in the urban scene of Area 1 (see Figure 3 and Figure 4).

Figure 3: IKONOS image of the urban test area



Figure 4: Aerial photograph of the urban test area



2.4.2 Roads.

All major roads could be captured with confidence. Minor roads in housing estates could also be captured. Some roads within estates were too small or indefinite to be captured with confidence, as the actual kerbs cannot be seen. In rural areas it was difficult to see whether a small highway was a metalled road or farm track.

For mapping purposes, major roads could be confidently captured using this imagery where they are not obscured by overhead detail. Roads within urban areas can also be depicted, but minor deviations may not be so clear. Narrow roads in rural areas are difficult to distinguish from farm tracks. This imagery could be used for capturing major roads at 1:10,000 scale and smaller, while small roads and larger-scale mapping would require field verification.

2.4.3 General line detail (fences, walls etc.).

The only fences captured were within housing estates, where the operator could 'expect' to see them and on field boundaries where there were sturdy fences. The only general line features which were easy to detect were large walls. The poor interpretation of these features is a major drawback should this form of imagery be considered for any mapping larger than 1:25,000 scale.

A major problem for Ordnance Survey is that the current specification for all mapping scales up to 1:50,000 show fences. The only general lines which were clear to capture, were substantial walls, substantial hedges and the edge of bridges. Using this mono digital imagery it is virtually impossible to confidently capture fences. It is expected that stereo satellite imagery would help in this area.

2.4.4 Railway detail.

The general alignment of the railway could confidently be depicted. This was helped by the educated knowledge of how railways would usually appear in an image (i.e. constant alignment with no sudden curves). However, the actual rails could not be seen and railway furniture (e.g. signals, points) was certainly not visible. It is very difficult to separate multiple tracks.

For mapping, major rail alignments can be captured for 1:10,000 scales and smaller. However, in urban areas where there are marshalling yards and multiple tracks it is very difficult to separate each track, and field verification would be required. Not recommended for 1:2500 mapping.

2.4.5 Paths.

Once a path is identified then it is easy to follow and capture. However, occasionally there were features which could equally be a path, track, stream or other linear feature.

Paths cannot be confidently captured throughout their entirety. However, the same can be said when using aerial photography. Field verification would have to be used at all scales to complete paths using this imagery.

2.4.6 Tracks.

The alignment of tracks was very easy to capture, but problems arose when trying to differentiate between tracks and small metalled roads.

2.4.7 Vegetation.

General vegetation was easy to depict although the actual nature of the vegetation is not easy to identify. This imagery would be suitable for mapping at scales ranging from 1:2500 to 1:50,000.

2.4.8 Forestry limits.

These were very easy to capture. Species and type of tree were a little more difficult to determine. However, it is possible to distinguish between wholly coniferous or wholly non-coniferous areas, indicating that this imagery would be suitable for 1:10,000 scales mapping and smaller.

2.4.9 Electricity poles / pylons.

Actual poles are difficult to identify, but the identification is greatly helped by shadows caused by the shallow sun angle. Pylons are a bit easier to identify. However, in both types the actual electricity lines cannot be seen, thus making the alignment of the whole line through the image quite difficult to follow.

Pylons and alignment could be captured for 1:10,000 mapping and smaller, while electricity poles would require field completion/verification

2.4.10 Water detail.

Lakes and ponds were easily identified and captured. Lakes would be acceptable for 1:10,000 mapping and smaller. Small ponds would require confirmation on the ground. The capture process would be helped using multispectral or pan-sharpened imagery.

2.4.11 Rivers and streams.

Rivers are quite easy to detect, but smaller streams are difficult to differentiate from paths. Multispectral, or pan-sharpened, imagery would make this task easier. It is also difficult to determine the width of a stream; and it is thought that stereo imagery would help in this process. The capture of rivers from this imagery would be acceptable for 1:10,000 mapping and smaller, but streams would require field completion to get a true picture of the topographic feature.

2.5 *Comment on results*

The identification of all of the features considered in this research would be improved greatly if stereo imagery was used. Previous studies at the Ordnance Survey (Ridley *et al.* 1997), analysing sub-sampled 1m aerial imagery, concluded that stereo imagery would increase identification by 20%. Although stereo data was not available for this project, stereo IKONOS imagery was viewed by kind permission of Professor Dowman at UCL, and

Derek Ireson at Z/I Imaging. Experience from these observations confirms this conclusion to be correct.

The use of stereo imagery would be strongly advised for inner-city urban areas, to alleviate the problem of height displacement.

This conclusion is not restricted to satellite imagery, the same can be said of aerial photography. In the photogrammetric department at the Ordnance Survey, both stereo and mono techniques have been used, and stereo imagery has been found to be the best option for feature extraction.

The use of 'pan-sharpened' imagery would also be of very useful assistance, especially in the capture of water features.

3 Positional accuracy

3.1 Objective

To assess the positional accuracy of the features surveyed from the image, along with the identification accuracy. The accuracy of High Resolution Sensor data will be compared with conventional survey methods (aerial photography).

3.2 IKONOS accuracy

The GeoProduct image supplied is the most basic IKONOS product sold by Space Imaging (details of image products can be accessed at:

<http://www.spaceimaging.com/level2/prodhigh.htm>). This is reported by Space Imaging to have been geometrically corrected to an accuracy of 50 meters not including the effects of terrain displacement. The Lucerne image is very interesting in that the terrain elevation varies from 2118 metres to 435 metres, providing a good test of Space Imaging's accuracy quotes. The image was found to be in error by 50 metres in the urban area of Lucerne at 435 meters elevation, compared to an error of 150 metres at the top of Mount Pilatus at 2118 metres elevation. On the basis of these inconsistencies, we do not recommend this form of Geo-correction of IKONOS imagery for large scale mapping.

One of the drawbacks of IKONOS imagery is that it was not possible to ortho-rectify the imagery using standard digital photogrammetric software, due to Space Imaging withholding the sensor model parameters needed for ortho-rectification. Space Imaging's business was built initially around producing ortho-rectified imagery as a value added product, and the 'Precision Product' costs 5 times more than the basic product. Table 2 below shows the accuracy expected from the products offered by Space Imaging.

Table 2: Product accuracy offered by Space Imaging. Note: CE90 is the circular accuracy with a confidence level of 90%.

Product code	CE90 accuracy
Geo	50m
Reference	25m
Map	12m
Pro	10m
Precision	4m

Since this project was initiated it has become possible for users to ortho-rectify IKONOS imagery themselves using the methods outlined below.

As reported by Thierry Toutin and Philip Cheng (Toutin and Cheng, 2000), the rectification of IKONOS images can be performed using several techniques – a simple polynomial method, the rational polynomial method, or the rigorous (or parametric) model method. The simple polynomial method only takes into account the planimetric distortions at each ground control point, and makes no allowances for the terrain. The rational polynomial method uses a ratio of polynomial functions, together with a DTM of the ground, to produce a more accurate rectification. The parametric approach takes into account the viewing geometry, the terrain, the satellite position and orientation, and the sensor model, to derive an accurate solution using a small number of control points. Toutin and Cheng (2000) show how a rigorous approach can be used without the full IKONOS sensor model and viewing geometry. Their technique uses the IKONOS imagery and its associated metadata to derive an approximation of the viewing geometry and the sensor characteristics. These, together with a set of ground control points, are then used within an orthorectification software package to produce a rectified image. Results show that the process generates images which are of comparable accuracy to those of the IKONOS Precision product. The report concludes that the process gives users with access to accurate ground control points the ability to orthorectify their own “Geo product” IKONOS imagery, at a much lower cost than the equivalent IKONOS “Precision product”.

(Note: A similar methodology to the above is detailed by Karsten Jacobsen (University of Hannover) in Annexe 3 of this report.)

A press release from PCI Geomatics

(http://www.pcigeomatics.com/pressnews/2001pci_si.htm) of June 18th 2001, states that there has been a large customer demand to have the ability to ortho-rectify the imagery themselves. This has led Space Imaging to release a new product - 'Geo Ortho Kit' -which allows the photogrammetric community to get more value out of their Geo Product. The Geo Ortho Kit comprises the base image product (Geo Product) and Image Geometry Model (IGM) file. The IGM is described as “a mathematical way of expressing the complex sensor model of IKONOS which is required to correct the image for terrain distortions”. The Geo Ortho Kit, together with the user’s own ground control points and a suitable DTM, will enable customers to orthorectify the imagery to a high level of accuracy.

Note: since the time of this research, several other vendors have released software enhancements enabling IKONOS Geo products to be orthorectified. These include products from Leica Geosystems (ERDAS Imagine and SOCET SET), Z/I Imaging (ImageStation) and Earth Resource Mapping (ER Mapper).

3.3 *Geometric accuracy*

As the solutions detailed in section 3.2 were not available at the time of the project, it was decided in this trial to initially ‘rubber sheet’ the image to map detail using 2nd order polynomial functions. A total of 40 points were used in each area. Ground control was in the form of the 1:25,000 scale raster map. The accuracy of these ground control points is not precisely known, but is presumed to be in the region of 8.0m RMSE. Table 3 below shows the differences between each product using the raster map as ground control. Also provided

for comparison was digital ortho-imagery created from aerial photography. The “relative error” listed in the table is calculated by comparing the distance between each pair of points in the target image with the distance between the same pair of points in the source image. The relative error is the root mean square of these differences.

Table 3. Accuracy of results comparing raster map, aerial photography and Area 1 (rural), 2nd order polynomial geo-corrected IKONOS image (all figures in metres).

	RMS error			Standard deviation			Mean error			Relative error	No. of points
	X	Y	Diag	X	Y	Diag	X	Y	Diag		
Raster v IKONOS	6.4	3.7	7.5	6.3	3.6	7.2	0.95	1.1	1.5	7.2 m	32
Aerial v Raster	4.0	2.8	4.9	3.5	2.6	4.4	-1.8	-1.1	2.1	4.3 m	35
Aerial v IKONOS	5.9	3.7	6.9	5.8	3.6	6.9	-.57	-.02	.57	6.8 m	32

Raster = Swiss raster map

IKONOS = Geo-corrected IKONOS Geo Product image

Aerial = aerial ortho-image

Table 4. Accuracy of results comparing raster map, aerial photography and Area 2 (mountain), 2nd order polynomial geo-corrected IKONOS image (all figures in metres).

	RMS error			Standard deviation			Mean error			Relative error	No. of points
	X	Y	Diag	X	Y	Diag	X	Y	Diag		
Raster v IKONOS			19.1			18.7			3.5	21.0 m	24
Aerial v Raster			7.2			7.0			1.6	6.8 m	24
Aerial v IKONOS			16.9			16.1			4.8	19.0 m	24

It can be seen from Table 3 and Table 4 that the results achieved in Area 1 are superior to Area 2. This was to be expected, because of the flat nature of the urban area. However, the results are still not adequate to produce a consistently accurate map from. This can be seen in Figure 5 Surveyed buildings plotted from a 2nd order polynomial geo-correction of the valley area of Area 2. *Note: the newly plotted buildings are in blue.*, where the detail plotted in Area 1, shows random positioning of the buildings. It is very important to point out that the raster map may also have inconsistencies. However, without the necessary ground truth these are only assumptions.

3.4 Relative error

As expected the relative errors in Area 1 (urban) were far less than in Area 2 (mountainous). However, as can be seen in Figure 5, the relative position of the buildings in relation to the raster map is not good. This is in contrast to the mountainous area of Area 2. where the position of the plotted detail was 30 metres out in places.

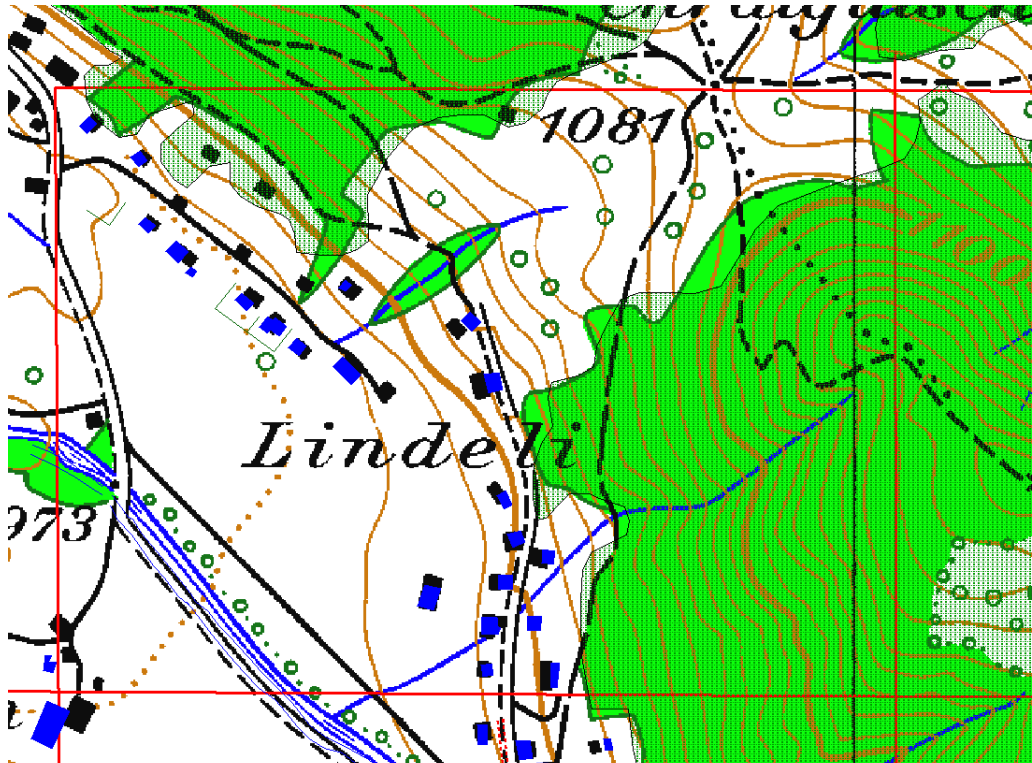


Figure 5 Surveyed buildings plotted from a 2nd order polynomial geo-correction of the valley area of Area 2. *Note: the newly plotted buildings are in blue.*

3.5 Geometric accuracy

Please note - See Figure 4 to view the IKONOS urban scene.

3.5.1 Height displacement

Because of the 67 degree collection elevation of the satellite at the time of capture there is consistent overthrow of buildings. This is particularly a problem on multi-level structures in the inner-city area of Lucerne. The shape of forests on hillsides is also affected by this height displacement. If this form of satellite imagery was captured from directly above the target, the height displacement would be minimal because of the very narrow look angle and distance from sensor to ground. However, in mountainous areas and urban areas there are clear height displacements in the original image. It is interesting to note that Space Imaging are now offering a minimum collection elevation level of 70 degrees with their GeoKit ortho product.

3.5.2 Alignment of linear features

The alignment of features in low-lying areas was relatively good. In mountainous areas, unless the image has been thoroughly ortho-rectified, there could be distortion of linear

features. The amount of distortion will depend on the planimetric accuracy achieved and the resolution of the underlying digital terrain model (DTM).

3.5.3 Shape of features

It was very difficult to confidently define the exact geometric shape of buildings, particularly housing. In dense urban areas it was difficult to depict building divisions and separate small buildings/extensions from the main buildings. It was often impossible to determine whether grey coloured features in back gardens were plots of land or buildings.

A high percentage of these problems would be solved by using stereo imagery.

3.6 Summary.

It can be seen that using the polynomial geo-correction method, the results are inconsistent and vary depending on the nature of the underlying elevation of the land. Therefore it would be difficult to recommend using this geo-correction method for Ordnance Survey map revision unless the area was very flat and enough ground control was available. However, if the imagery was only purchased for change detection, currency checking or a general overview of an area then this correction method may be of use. This is because of its ease of use, economy and general availability of the software.

Assuming that the figures quoted by Space Imaging and PCI are correct an accuracy of 4m RMSE can be achieved using one of the following methods (more details in Section 3.2):-

1. Space Imaging 'Precision' product (customer supplies GCP's and DTM)
2. Space Imaging 'Geo Ortho Kit' product
3. Purchase PCI Geomatics 'IKONOS Geo Model' solution, to ortho-rectify basic 'Geo Product'

The accuracy expected of Ordnance Survey's basic scale mapping is as follows:-

Scale	RMSE
1:2500	2.47m
1:10,000	4.75m
1:25,000	9.0m
1:50,000	20m

3.7 In conclusion,

- 4m RMSE absolute accuracy is acceptable for Ordnance Survey base mapping scales of 1:10,000, 1:25,000 and 1:50,000.
- This imagery cannot reach the accuracy of 1.1m RMS required for Ordnance Survey 1:2500 positional accuracy improvement (PAI) programme.
- To ortho-rectify this imagery using the methods of section 3.2 would be straightforward in the UK, where there is an abundance of ground control.
- To ortho-rectify this imagery would require far less ground control than an aerial triangulation scheme, used for aerial photography. This has advantages in developing countries and remote areas where the acquisition of ground control can be impractical and expensive.

4 Cost benefits

4.1 Objective

To carry out a cost benefit analysis of using High-Resolution Sensor data over conventional methods (aerial photography).

4.2 Cost analysis

To look at the costs of using this form of imagery the whole map revision process has to be examined and not just the cost of the raw product. It has to be remembered that the cost of acquisition and control of aerial photography in the map revision process is under 10% of the final cost. Therefore it is necessary to evaluate the percentage cost of using this imagery over the whole flowline of map revision.

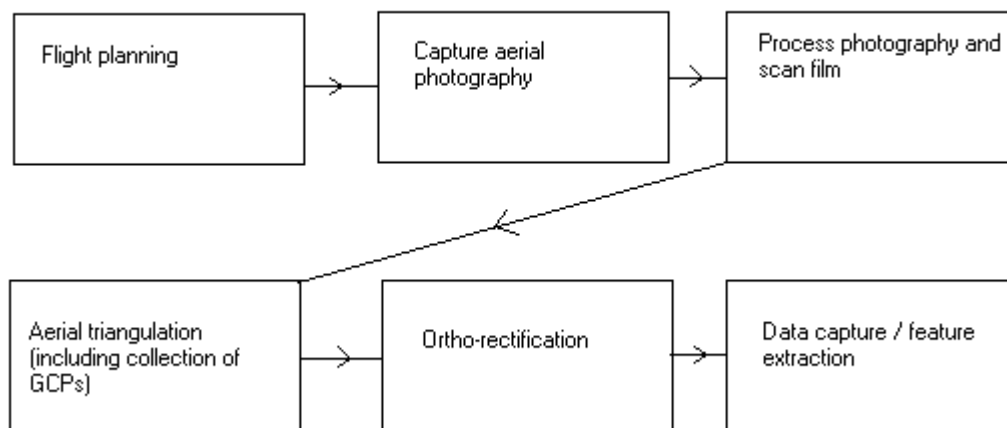


Figure 6. Flow diagram of a typical photogrammetric map revision flowline

For this project a typical 10 x 20 km square block of Ordnance Survey 'mountain and moorland' cyclic revision work will be evaluated (200 square km's). This is for 1:10,000 basic scale mapping.

Table 5 Flowline costs

Process	Aerial photo	Geo Product	Precision product	Geo Ortho-Kit	PCI product
Flight planning	Total = £6000	Total = £7000	Total = £27,200	Total = £12,400	Total = £7000
Imagery					
Aerial triangulation					
Ground control	20 points	0 points	0 points	6 points ?	10 points ?
DTM	£800			£800	£800
Ortho-rectification	£500	0	0	£200	£200
Accuracy achieved	Rms. 2.5m	+/- 50m	Rms. 4.0m	Rms. 4.0m	Rms. 4.0m
Data capture	£4400	£4400	£4400	£4400	£4400
Total	£10,900	£11,400	£31,600	£17,000	£11,600
difference over aerial photography		+£500	+£20,700	+£6,100	+£700

Please note: - If users wish to task the satellite to capture IKONOS imagery of a specified area of their choice then there is an additional cost of \$3000 for this privilege.

4.3 Notes.

- These figures assume the use of 1m panchromatic digital ortho-imagery
- These figures are for map revision. If the same figures were applied to the capture of new mapping then the cost effectiveness of the IKONOS imagery becomes more attractive, due to the smaller percentage of imagery-cost against the cost of the whole project.
- Aerial photography is more costly to **control** because of the need to use aerial triangulation to control the strips of photography.
- The IKONOS image is a single image requiring one single ortho-rectification and less ground control. It is thus very useful as a 'snapshot' image taken within a very short period of time.
- To ortho-rectify IKONOS 1m panchromatic imagery, it would be advisable to run a test to evaluate which is the most economic option. These options are to use the Space Imaging 'Geo Ortho Kit', or PCI 'Geo Model' software.
- The PCI figures relate to the use of their custom software to enable rectification of IKONOS 'Geo Product' imagery. The cost of this software (IKONOS Geo Model) is £2730 above the standard Geomatica 'Fundamentals' software costing £2275. These costs would have to be added to any business case connected to using this method.
- The use of IKONOS data and orthorectification software puts this imagery in direct competition with aerial photography, for large area coverage.

- These figures relate to the Ordnance Survey where the availability of aerial photography, ground control, a Digital Terrain Model and aerial triangulation systems is taken for granted. High resolution satellite imagery is even more attractive in developing countries and remote areas where these resources are not so plentiful.

5 System maturity

5.1 Objectives

To investigate the maturity of software system products used to complete the topographic mapping.

5.2 Products available

The prices of the products available from Space Imaging at the time of this project are given in Table 6.

Table 6: The basic products offered by Space Imaging (in 2001). These prices are per square kilometre. A minimum order of \$1000 for USA and \$2000 for International orders is required.

Product code	CE90 accuracy	USA price	International price
Geo	50m	\$12	\$29
Reference	25m	\$29	\$73
Map	12m	\$39	\$98
Pro	10m	\$49	\$122
Precision	4m	\$66	\$149
Geo Ortho Kit	4m		\$62

(CE90 is the circular positioning accuracy with a confidence level of 90%)

To achieve the accuracy of the Precision products, the customer must provide the digital elevation models (DEM) and ground control points (GCP's), so the accuracy of the end product is limited by the accuracy of these ingredients.

Toutin and Cheng (2000) report that sub-pixel accuracy will not be achievable with IKONOS imagery and that the accuracy figures quoted by Space Imaging are correct.

The release of the Geo Ortho Kit (see section 3.2) is a significant move by Space Imaging and, for national mapping agencies who have plentiful GCP and DEM information, this move makes the IKONOS imagery even more attractive. However, this still entails the ortho-rectification of the imagery.

5.3 Hardware / Software requirements

At the Ordnance Survey, photogrammetric map revision is carried out using the following digital photogrammetric systems.

1. Z/I Imaging workstations for aerial triangulation (ISPM)
2. Z/I Imaging workstations for digital ortho-image production (Ortho Pro).
3. L/H Systems SOCET SET for stereo data capture.
4. Laser Scan, Lamps 2 as mapping editor.

It has been established that IKONOS 1m panchromatic ortho-imagery imagery can be loaded and used **for manual feature extraction** using the L/H Systems SOCET SET digital photogrammetric workstations used at Ordnance Survey.

It has also been established that these systems can also be used for feature extraction from IKONOS **stereo imagery**. **Please note** that to enable viewing of an IKONOS stereo pair it is necessary to be able to read the RPC (rational polynomial coefficient) support file attached to the images.

If it was decided to ortho-rectify images using Space Imaging's Geo Ortho Kit product, then a suitable ortho-rectification system would be required. At present ERDAS, ER Mapper and PCI Geomatics have announced that their systems can process Geo Ortho Kit products. However, it appears that most major ortho-rectification systems vendors are quickly producing systems which can process this product.

5.4 Trends in Geographic Information

It has been shown in this project that it is possible to create mapping from IKONOS imagery. Although not perfectly compatible (i.e. not as suitable as aerial photography at the current specification) with any current Ordnance Survey basic mapping scale (1:1250, 1:2500 or 1:10,000), this imagery can produce a very clear base map which highlights the main topographic features within an area. The danger would be to expect too much from this imagery and it is necessary to focus on its strengths.

As stated in the introduction to this Annexe, there is a growing demand for the following

1. up-to-date topographic mapping
2. digital ortho-imagery as a mapping backdrop to GIS systems

This imagery would be very suitable as an image backdrop to a mapping GIS, particularly in remote areas and developing countries. In developing countries where there are few resources for creating and up-dating line mapping, this imagery could make a very attractive, economic form of digital ortho-imagery. The importance of geo-rectifying the imagery to a good standard cannot be underestimated, and this would have to be given careful consideration, particularly in view of the amount of ground control and quality DEM required for the image correction. Image maps are one of the more attractive products which could be derived from this imagery.

Image Maps. Figure 8, shows a basic Map created from Area 1. This took approximately 4 hours to capture and is of a very basic specification. However, when the vector map is accompanied by the IKONOS image, the information on this map increases dramatically. Figure 7 shows an Image Map extracted from Area 1 (urban).

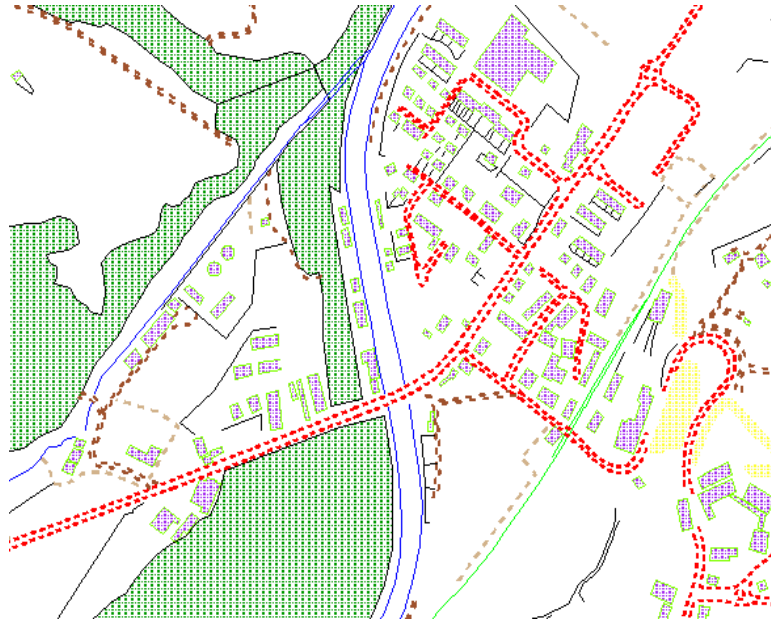


Figure 8. Base map extracted from Area 1. of the IKONOS image



Figure 7. Imagemap extracted from Area 1. of the IKONOS image.

5.5 Examples of the use of IKONOS imagery.

There are several examples of the use of this imagery on the Space Imaging website (www.spaceimaging.com) and elsewhere on the Internet. Two interesting projects are described below.

5.5.1 Jamaica

<http://www.spaceimaging.com/newsroom/releases/2001/jamaica.htm>

This explains how the Jamaican government intends to utilise this imagery throughout their government departments. It is envisaged it will be used in the following disciplines: -

- Telecommunications
- Planning
- Cadastre mapping
- Farming
- Housing
- Real estate
- Public safety
- Emergency response
- Population/demography response

5.5.2 High Resolution Mosaic for Flood Damage Assessment in Venezuela

(http://www.ccrs.nrcan.gc.ca/ccrs/comvnts/rsic/2901/2901ra5_e.html)

This exercise involved the ortho-rectification of four IKONOS Geo Product images, using the PCI Geomatics, CCRS-developed IKONOS model. The area covered was 60 km by 10 km in area. Although only six control points would be required to correct each image, in this case 30 GCPs were used. Using the block of images, they were able to produce ortho-images with the following RMS Residuals, 3.5m in X and 3.8m in Y. This incorporated a DTM of 5m accuracy, which did limit the end result.

The article shows an example of existing 1:1000 mapping overlaid on the image, which gives a visual impression of the accuracy achieved. This is a very interesting reference and could be used as proof of achievable accuracy.

6 Conclusions and recommendations

6.1 Conclusion

In this exercise it has been shown that IKONOS imagery has potential for topographic mapping. This is particularly so in developing countries and remote areas, where the cost of topographic mapping/revision from traditional photogrammetric methods can be prohibitively expensive and impractical.

All Ordnance Survey mapping has a rigid map specification, which is very detailed and suited to current revision methods and traditional user demand. These specifications are rarely altered. In comparison to the Swiss 1:25,000 mapping provided for this trial, Ordnance Survey's 1:25,000 specification shows more features **including fences**. Because fences and other small linear features are very difficult to extract from this imagery, this

precludes this imagery for use in Ordnance Survey map revision for any scale below 1:50,000 without extensive field completion, under the current specification. There are two ways of using this imagery for revision of Ordnance Survey mapping below 1:50,000 scale:

1. Change the map specification
2. Change the requirement of what features will be revised (i.e. only major topographic features)

There is growing expectation/demand from map users of Ordnance Survey mapping products to have the maps as up-to-date as possible. The OS use aerial photography for quality checking the currency of mapping. IKONOS imagery is a viable alternative form of imagery for this purpose, particularly in respect to the ease of ortho-rectification and large area coverage. However, for major topographic change detection SPOT satellite imagery (panchromatic, 5m GSD imagery) would probably serve the same purpose and is more readily available and economic to use.

At present IKONOS imagery suffers from poor availability and uncompetitive price when compared with aerial photography in the UK. The launch of other satellites with 1m resolution sensors should increase competition for this type of imagery and drive costs down. These new sensors will be Quickbird2 and Orbview 4, due to be launched in Autumn 2001 (note: since this was written, OrbView4 suffered a launch failure and is believed to have burnt up in the Earth's atmosphere, while QuickBird was successfully deployed in orbit). As for availability, it is felt this will improve once commercial users can be given as high a priority as Government/military customers.

It has been demonstrated that the imagery used in this trial has similar drawbacks to digital mono panchromatic aerial photography, such as:

1. Problems caused by height displacement
2. Cloud cover
3. Difficulty of feature interpretation in dense urban areas
4. Feature capture would be greatly helped by stereo coverage, and by the use of "pan-sharpened" imagery of multispectral imagery combined with the panchromatic imagery.

The products which may be created from IKONOS imagery include:

1. Hard copy image maps for leisure and recreational use and direction finding.
2. Digital image layers within a GIS
3. Low specification medium scale national vector mapping derived from the imagery
4. A consistent topographic detail change database could be created using regular 'snap-shot' imagery.

6.2 Recommendations

1. To be used for Ordnance Survey map revision, a change to the mapping specification would be required. Using Ordnance Survey map specifications as a guide, IKONOS imagery could be used for revision of mapping at the following scales:

1:50,000 – for full specification

1:25,000, no small linear features – reduced specification

1:10,000, no small linear features – reduced specification

1:2500 – not recommended

2. If this imagery were to be used for revision of Ordnance Survey mapping at 1:2500, 1:10,000 and 1:25,000 scales, it is recommended that extensive field completion be carried out.
3. This imagery is recommended as a tool to aid small scale surveyors, providing them with a 'snapshot' of their area of interest.
4. The use of this imagery for quality monitoring of map currency and detection of major topographic change would be highly recommended, particularly because of its large 'snapshot' areas, which can easily be ortho-rectified.
5. If it was decided to use this imagery for a change detection trial, it would be advisable to evaluate SPOT imagery at the same time.
6. It is recommended that Pan-sharpened, multispectral and stereo IKONOS imagery be evaluated for feature extraction alongside the panchromatic data.
7. Users not familiar with the requirements/technicalities of digital ortho-imagery created from aerial photography would find the use of the 'Precision' IKONOS orthoimage product easy. This gives GIS users access to a product which is cheaper than high specification Government mapping, but would satisfy many of their demands (see Image Map, Fig. 7). National Mapping Agencies should be aware of this potential threat.
8. The ease of use of this imagery is also an advantage to developing countries and remote areas..

(Note: references for all the annexes are included in the references of the main report.)

Oeepe – Project
on
Topographic Mapping from High Resolution Space Sensors
Report by Anders Rydén and Jan Sjöhed
National Land Survey of Sweden
Work package 1 – ‘High Resolution Sensor Data for Topographic Mapping’

1 Aim and objectives

The major aim of the work package 1 is to investigate the potential of high spatial resolution satellite imagery in the detection and update of topographic features. The objectives are:

- To survey the topographic features in a defined area, and feature coding according to a specification.
- Assess the positional accuracy of the newly surveyed features, along with the identification and interpretation accuracy. The accuracy of using High-Resolution Sensor data will be compared with conventional survey methods (aerial photography).
- Assess the cost benefit analysis of using High-Resolution Sensor data over conventional survey methods (aerial photography).
- Investigate the maturity of software system products used to complete the topographic mapping.

The work reported covers the findings as far as the materials available have allowed.

2 Methods

The high-resolution image evaluated is the IKONOS multispectral image (4 metres resolution) covering Chandlers Ford, an area north Southampton, UK. The four spectral bands of the IKONOS image were supplemented by one raster image from Ordnance Survey. Analogue plots of the image at a scale of 1:20 000 were also used. The plotting was done on an HP2500 inkjet plotter.

The evaluation was carried out on-screen, partly using the Erdas "Viewfinder" software supplied through the project, partly using the "Erdas Imagine" software available at Lantmäteriet. Field control (collection of "ground truth" data) was not carried out – the evaluation is entirely based on assessment from the image itself and on general experience of the area.

The image has been evaluated against the Swedish specification for the digital database used for the Swedish 1:10 000-scale map. Four different topographical settings have been chosen for the evaluation; built-up areas, communication, land use and vegetation, and drainage. Two different band combinations have been evaluated; one resembling a normal colour photograph, and one resembling an infrared aerial photograph.

3 Results

The results are presented according to the four general themes used in the evaluation, i.e. built-up areas, communication, land use and vegetation, and drainage. For a more detailed assessment of the capabilities of the composites, gamma corrections have been applied, which unfortunately was not possible to illustrate in the figures below. The following section gives an outline of the general findings from the evaluation.

3.1 Built-up areas

Figure 1 shows two sub-scenes for built-up areas, represented by the two different band combinations chosen. The upper left corner of the sub-scenes shows an industrial area, characterised by large buildings, and the rest of the sub-scenes show typical residential areas

with semi-detached houses and tree-lined back gardens. The sizes of the properties in the residential area are typically between 0.05 and 0.1 hectares.



Figure 1. The figure shows two sub-scenes for built-up areas, represented by the two different band combinations. The approximate scale is 1:10 000.

Built-up areas are easy to distinguish and delineate, and based on context and pattern it is possible to characterise the delineated areas into residential and industrial/commercial. Other prominent built-up features, such as cemeteries and recreation areas are equally easy to identify. Mapping the edges of the roofs, as specified for buildings, is only possible for larger buildings.

Public institutions, usually larger in size than surrounding buildings, are easily detected in the images. However, unless the institution possesses some distinct attributes visible in the image, the identification demands some local knowledge. Other buildings, such as larger sheds, barns and storehouses can be detected although they may be difficult to identify and map correctly. Smaller buildings (cabins, small public institutions, ruins, etc), may only be detected based on contextual information and associations with other features. Smaller estates sometimes tend to blend into the surroundings.

Within the residential area it is difficult to separate the different houses. This is partly due to the characteristics of semi-detached houses, partly due to the resolution which makes the image a bit too coarse for the purpose. However, in areas with larger houses, it may be possible to map the centre point of each house/property, but then only if the interpreter is well acquainted with the area.

When displaying the image using the default linear stretch, areas such as the industrial/commercial tend to become a little bit too bright and the dynamics subdued. However, if the gamma curve is adjusted, some further details can also be identified in the industrial area that is over-bright in figure 1. This effect is especially notable in the natural colour band combination. If the gamma correction is suitably adjusted, more details on the roofs such as larger pipes and vents appear and can be identified. This process will, however, suppress details in other areas. Delineating the outline of buildings is only possible for larger buildings.

3.2 Communication

Figure 2 shows two sub-scenes covering part of the transportation network, represented by the two different band combinations chosen. South of the highway is a residential area, with houses shown as brighter spots in the vegetation. In the upper right corner and along the right side of the sub-scenes a golf course is visible – characterized by the sand bunkers.

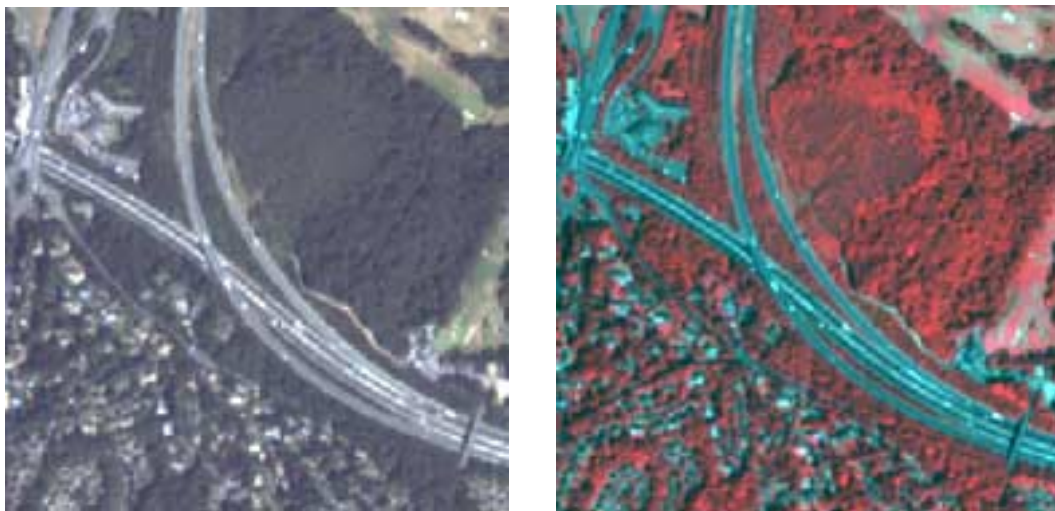


Figure 2. The figure shows two sub-scenes for evaluation of the road network, represented by the two different band combinations. The approximate scale is 1:10 000.

In the images, major roads are clearly visible and the resolution makes it possible also to roughly determine the number of lanes in each direction. Cars on the major roads are seen as bright spots although when zoomed too close they disintegrate. Bridges and elevated roads are easily distinguishable based on the shadow while the context may have to be used for identification of smaller bridges.

Railways are not as pronounced as roads in the image. The contrast between railways and the surrounding areas is low, which makes them less easy to distinguish and identify. For other linear features such as power lines, the identification can only be done based on associations.

In the countryside the impression is that minor roads and most motorable tracks are distinguishable, although smaller features such as small tracks and footpaths are not easy to detect accurately and may be heavily dependent upon the context and the contrast of the surroundings. It is also difficult to determine whether a linear feature is a small road or a tree-lined fence, hedge or a ditch.

Within residential areas, features such as the centre lines of the streets are distinguishable, although it may be difficult to map them accurately without having a good knowledge of the characteristics of the area. The relatively coarse resolution and the heterogeneous signature gives the images rather blocky textures if zoomed too close, which is difficult to interpret. However, by elaborating the gamma curve, some of this can be suppressed, giving a more easily interpreted image as related to the mapping of the street network.

As for built-up areas, major point features such as railway stations are possible to detect and map accurately according the specification, while smaller features such as communication masts and power stations, may only be detected based on contextual information.

3.3 *Land use and vegetation*

Figure 3 shows two sub-scenes covering an agricultural and forested area, represented by the two different band combinations chosen. The forested area is in the lower left of the sub-scenes intervened by what appear to be a wetter area with low, possible shrubby or rejuvenating, vegetation. The agricultural fields are at the upper half of the sub-scenes and the brighter scar in the middle might be exposed topsoil.

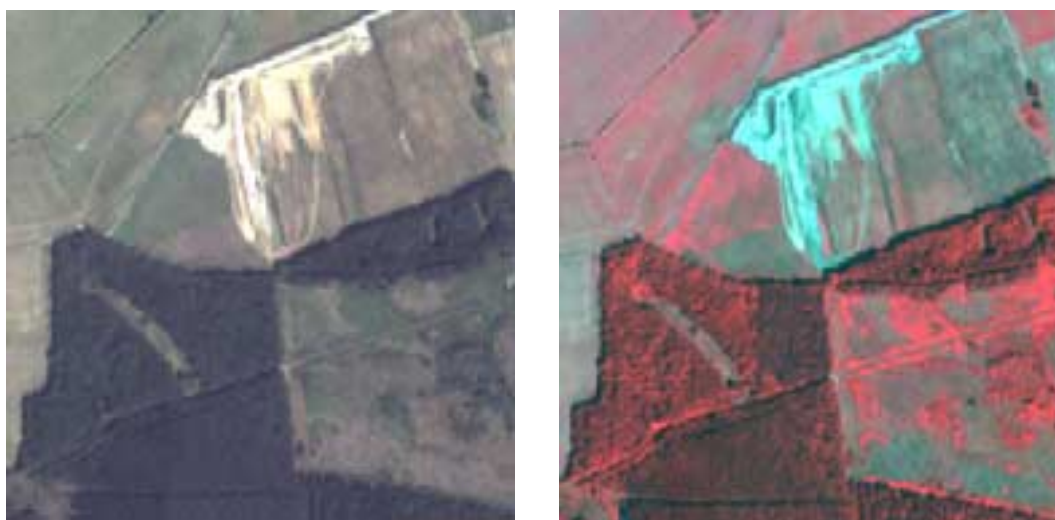


Figure 3. The figure shows two sub-scenes for evaluation of land use and vegetation, represented by the two different band combinations. The approximate scale is 1:10 000.

As expected, the infrared combination provides a better discrimination of features related to the theme land cover and vegetation. For the land use and vegetation, the infrared band combination is the easiest image to interpret. Tonal variations within the fields reveal the impact from the water-holding capacity of different soil compositions on the growth of the newly planted fields. Exposed soil, however, is clearly distinguishable in both band combinations, as are the field boundaries. As compared to the specification, only some few features, such as horticulture, may demand extra care during interpretation. Such features may not be as easily identified as detected and delineated.

The infrared band combination applied in forested areas reveal several different reddish tones indicating the suitability to distinguish between different tree types and compositions as well as indicating clear-cut areas. The resolution of the data and the spectral characteristics in the infrared also provide the interpreter with the shadow from the higher trees allowing height to be roughly determined as well. There is also an increased possibility of using indicators such as texture and pattern for identification/separation of features such as fields/meadows.

3.4 Drainage

Figure 4 shows two sub-scenes covering part of the drainage network, represented by the two different band combinations chosen. The drainage lines are represented as darker meandering features lined by vegetation. In-between the drainage lines are agricultural fields and meadows. In the lower right corner of the image, part of a dam or pond is visible.



Figure 4. The figure shows two sub-scenes for evaluation of the drainage network, represented by the two different band combinations. The approximate scale is 1:10 000.

For this theme, as with the vegetation theme, the infrared band combination is somewhat better for detection and identification. Open water has a black, easily distinguishable signature in the image. Also the different reddish tones of nearby vegetation are good indicators when interpreting drainage features. Major features, such as lakes, larger ponds and dams are easily delineated in the images, as are wider streams. The infrared band combination also makes it easy to correctly determine shorelines and to identify aquatic vegetation that is sometimes difficult to see in black and white aerial photographs.

Important for Swedish conditions, especially in the northern part, is the detection and delineation of wetlands. It appears, however, that such features would be possible to delineate with good accuracy, partly due to the high resolution as compared to previous satellite data, but mostly due to the infrared image which has colour information not present in black and white aerial photographs. This may also allow the interpreter to distinguish between the number of different wetlands specified in the database.

Smaller features, such as furrows and ditches, are distinguishable only based on associations, generally the vegetation lining. Although this may not pose any problem of delineating, the identification becomes less accurate. The same appears to be valid for point features. Major rapids and waterfalls are likely to be distinguishable while minor, man-made structures may pose some problems, as the resolution is not high enough.

4 Concluding remarks

The findings of this evaluation yield that for the Swedish digital database, also used for the Swedish 1:10 000-scale map, the multi-spectral IKONOS data is suitable to use for update of most features in the map as stated in the specification. A summary of the findings is presented in table 1. For the geometric accuracy, the image should in theory be good enough also for revision of the database although it has not been possible to evaluate the geometric accuracy during this work.

The evaluation has only been done based on the image itself and little contextual data has been used. This meant that no evaluation to determine errors of omission and commission has been undertaken. For this to be done, a full-scale test would have to be carried out in an area the interpreter is familiar with. For updating, however, the overlay of digital vector data would be a good aid for an evaluation of the operational usage of the image in ordinary production.

A definitive advantage with the IKONOS data is the availability of several bands allowing the image to be displayed in different combinations. This allows the viewer/interpreter to select the band combination that best suits the purpose of the application. As compared to lower resolution satellite data, the IKONOS data also provides the interpreter with an extra indicator not common in satellite data interpretation, i.e. the shadow.

Table 1. The table gives a summary of the major findings of the evaluation of the IKONOS multi-spectral data for the Swedish 1:10 000-scale map.

<i>Theme</i>	<i>Major findings</i>
Built-up areas	For aerial features, such as boundaries of industrial and residential and recreational areas, and for detection of point features, the IKONOS multi-spectral data is suitable for updating. The resolution, however, is not enough to enable identification and outline of details such as small houses. They may, however, be marked as point objects based on the image alone.
Communication	For line features, such as roads and railways, the IKONOS multi-spectral data is suitable for updating of the 1:10 000-scale map. Point features such as railway stations are also possible to detect and identify. Other point features are possible to detect but not to identify.
Land use and vegetation	For land use and vegetation the IKONOS multi-spectral data is suitable for delineation and identification of all the different features as specified for the Swedish 1:10 000-scale map.
Drainage	For drainage features, such as rivers and streams, the IKONOS multi-spectral data is suitable for updating of the 1:10 000-scale map. Point features such as waterfalls and rapids area also possible to detect and identify. Minor man made structures represented as point objects in the 1:10 000-scale map may be possible to detect but not necessarily to identify.

The discussion and conclusions drawn from this evaluation are the authors and do not necessarily reflect the opinion of Lantmäteriet.

OEEPE – Project
Topographic Mapping from High Resolution Space Sensors
Report by Karsten Jacobsen
Institute for Photogrammetry and GeoInformation
Work package 1 – ‘High Resolution Sensor Data for Topographic Mapping’
Geometric Aspects Of Ikonos Images

1 Introduction

Images taken by the IKONOS are today the highest resolution space data available for civilian applications. The original images of the line scanner camera are not distributed; only derived data can be purchased from the “CARTERRA” product line. The low-priced product, CARTERRA Geo, a rectification to a horizontal surface – is used most often. With knowledge of the geometric characteristics of the image, together with suitable ground control data, it is possible to upgrade the Geo-product to an orthophoto and to determine ground positions with much greater accuracy. This requires an expensive stereo pair of images or a digital elevation model (DEM).

2 IKONOS images

The imaging system of IKONOS can produce panchromatic (pan) (black and white) with at the highest resolution or multispectral (ms) images with a resolution 4 times lower. The original pixel size on the ground is depending upon the view direction (nadir angle) which can be changed in the orbit, but also the across direction by $\pm 52^\circ$.

$$\begin{aligned} \text{pixel size on ground in view direction} \quad pv &= 0.82\text{m} / \cos^2 V & V &= \text{nadir angle} \\ \text{pixel size on ground across view direction} \quad pc &= 0.82\text{m} / \cos V \end{aligned}$$

Formula 1: original pixel size on ground for pan-images

nadir angle	0°	10°	20°	30°	40°	50°
pan across view direction	0.82	0.83	0.87	0.95	1.07	1.28
pan in view direction	0.82	0.85	0.93	1.09	1.40	1.98
ms across view direction	3.28	3.32	3.48	3.80	4.28	5.10
ms in view direction	3.28	3.38	3.71	4.37	5.59	7.94

Table 1: original pixel size on ground [m] depending upon view direction

The pixel size across the view direction (= in orbit direction) results in an oversampling. The oversampling does not change the geometry – only the radiometric characteristic will be influenced by a low pass effect – leading to a reduction in contrast. A low contrast usually will be more than compensated by a contrast enhancement (indicated by the field: “MTFC Applied: Yes” in the meta data) but of course any information lost in the oversampling process cannot be brought back. Only derived products are available from Space Imaging, the operators of the satellite. The derived products are resampled with a square pixel format – for the pan-images with 1m x 1m and for the multispectral images with 4m x 4m. This corresponds to a small loss of information for near-nadir images, while for images exceeding a nadir angle of 25° the original information is below the nominal pixel size of 1m or 4m.

	pan	band 1	band 2	band 3	band 4
spectral range	0.45 - 0.90 b/w	0.45 - 0.53 blue	0.52 - 0.61 green	0.64 - 0.72 red	0.77 - 0.88 near infra- red

Table 2: spectral range of IKONOS images [μm]

The spectral range of the panchromatic image and the multispectral channels are shown in table 2. It is possible to combine the color information of the lower resolution together with the high resolution panchromatic data; using for example an IHS-transformation (see below); the basic requirements for this are geometrically fitting multispectral and panchromatic images. After exactly matching the images, pixel by pixel, the multispectral images are blown up to the same pixel size as the panchromatic channel (copy of 1 pixel to 4x4) and the red/green/blue (RGB) colors are transformed to intensity, hue and saturation (IHS). The intensity from the multispectral images is replaced by the panchromatic image, then the image is back-transformed to RGB. The result is a colour image with the spatial resolution of the panchromatic image. If no simultaneously recorded multispectral and panchromatic scenes are available, usually this process can only be done based on geometrically correct orthophotos. Such products are also available from Space Imaging as “Pan-Sharpned” (PSM).

The quantization of the gray values is 11 bit, corresponding to a range of 2048 gray values. The human eye is not able to use such a differentiation, it is limited to approximately 60 gray values, but it can adapt itself to the general gray level, separating objects in bright areas and also in shadows. The large range of the gray values for the IKONOS images have the advantage of the generation of optimal images, which can be used for both bright and dark areas within the image.

The imaging system of IKONOS, build by Kodak, is equipped with a Kodak linear array of 13 816 pixels for pan and 3454 pixels for multispectral, corresponding to a swath width of 11.329 km for a nadir view up to 29.889km for a nadir angle across the orbit direction of 52°. The flying height varies between 678km and 682km (mean 681km) above mean sea level. The inclination of the satellite orbit against the equator is 98.2°, resulting in a sun-synchronous orbit – the satellite always takes images at the same local time of the day - at approximately 10:30.

CARTERRA -	horizontal accuracy	vertical accuracy	
Geo	50m	-	system corrected to earth ellipsoid and specified map projection
Reference	25m	22m	ortho rectified without control points (DEM with +/-22m required)
Map	12m	10m	ortho rectified without control points (DEM with +/-10m required)
Pro	10m	8m	ortho rectified without control points (DEM with +/-10m required)
Precision	4m	4m	ortho rectified with control points (DEM with +/-4m required)
Precision Plus	2m	3m	ortho rectified with control points (DEM with +/-3m required)

Table 3: IKONOS- (CARTERRA-) products with accuracies claimed by Space Imaging

The satellite includes a GPS-receiver and 3 star trackers, allowing a declared stand alone geo-location of +/-12m for X and Y and +/-8m for Z. Of course these are standard deviations which can be exceeded in any individual case and which do require a corresponding height accuracy from a stereo scene or a suitable Digital Elevation Model (DEM). The geo-location is recorded in the WGS84-system. To convert this to the national or local coordinate system, a suitable transformation between the local datum and WGS84; and a model of the local Geoid undulation; is required. Based on control points, the CARTERRA Precision Plus can attain a horizontal accuracy of +/-2m and a vertical accuracy of +/-3m.

3 Image Geometry

Satellite line scanner images have a geometry different from perspective photos. For each line we have a *different* exterior orientation – the projection center (X0, Y0, Z0) and also the attitude data (phi, omega, kappa) change from line to line. However, the satellite orbit is very regular, allowing the determination of the relationship between neighbouring lines and also the whole scene based on the orbit information.

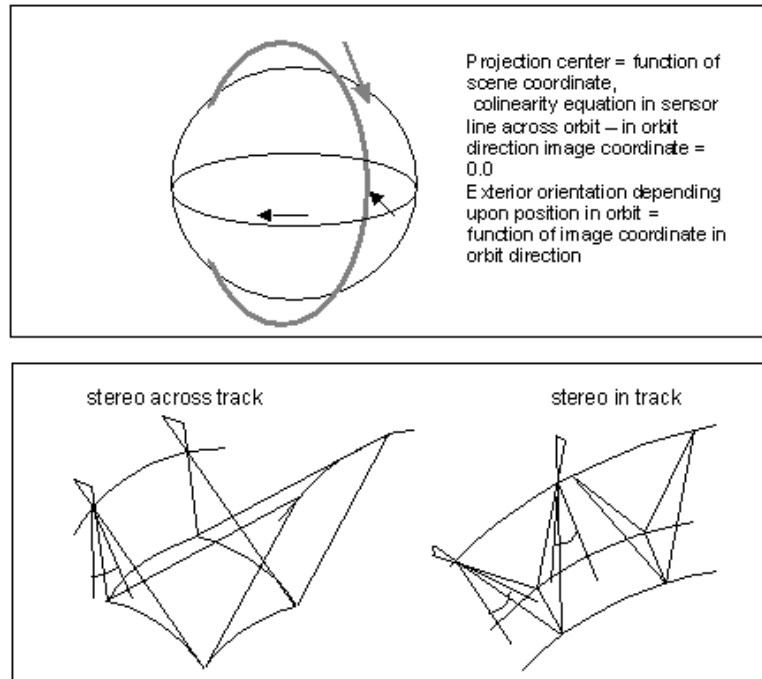
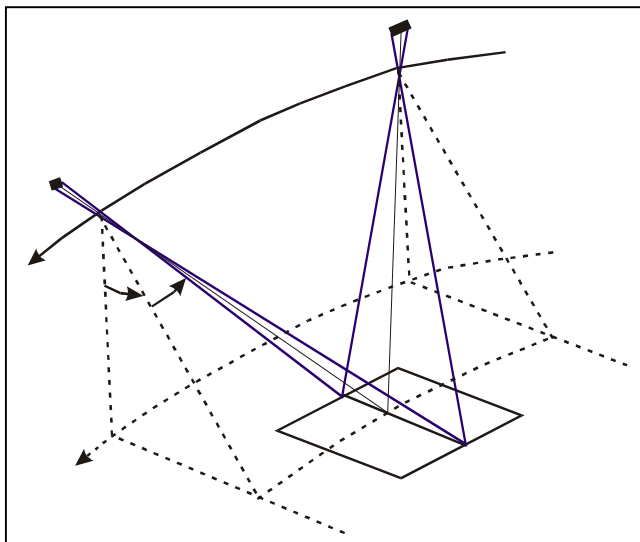


Figure 1: original geometric relation of satellite line scanner images.

Based on rough information about the satellite orbit, the geometric relation of such satellite line scanner images can be determined based on just 4 control points using software such the Hannover program BLASPO. But as shown in table 3, Space Imaging does not distribute the raw images – only derived products are available. Of course all the required products are available from Space Imaging, but for a very high price and the control points together with the DEM has to be supplied to Space Imaging. To upgrade the CARTERRA Geo product to a higher accuracy level, a special mathematical solution is required.



**Figure 2:
different view directions
possible from IKONOS**

IKONOS can change the view direction very fast, so a stereoscopic coverage is possible within the same orbit. The viewing across the orbit is required for a sufficient revisit of the same area. With an original pixel size of 1m, the same area can be imaged again after 2.9 days; with 1.5m original pixel size after 1.5 days.

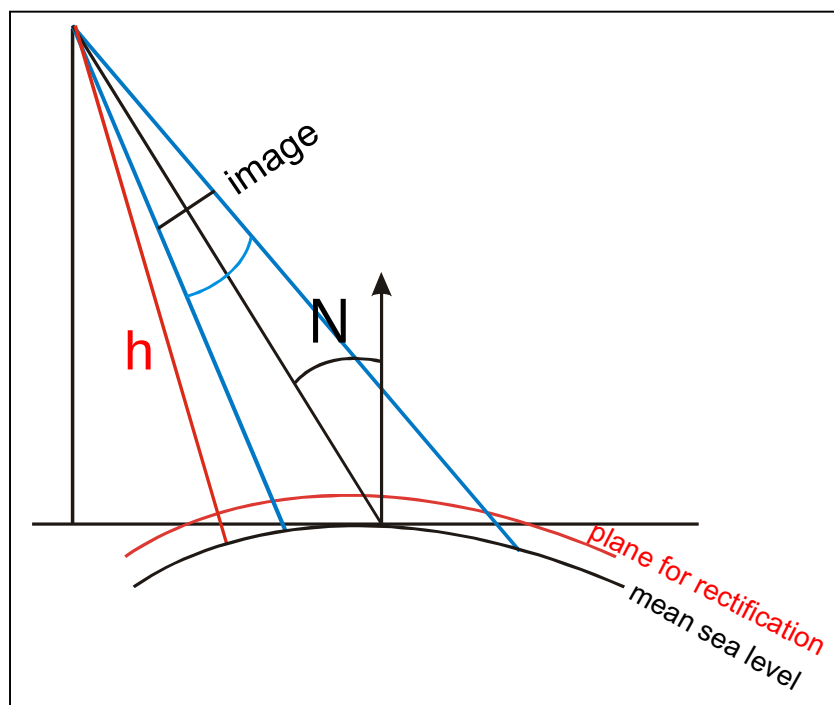


Figure 3:
geometry of
CARTERRA Geo

The Geo-product is rectified to a specified plane parallel to the earth ellipsoid. Beside the remaining errors of the image orientation, the geometry of such rectified images is influenced by the local height (see fig. 4), the geoid undulation and also the relation of the national coordinate system to WGS84 (datum).

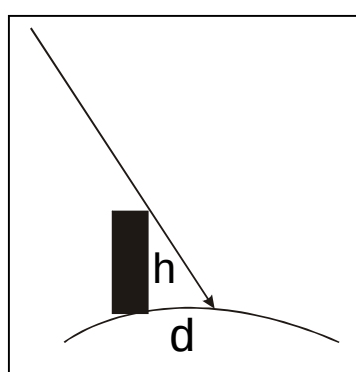


Figure 4:
geometric displacement of an object located above the
plane for rectification.

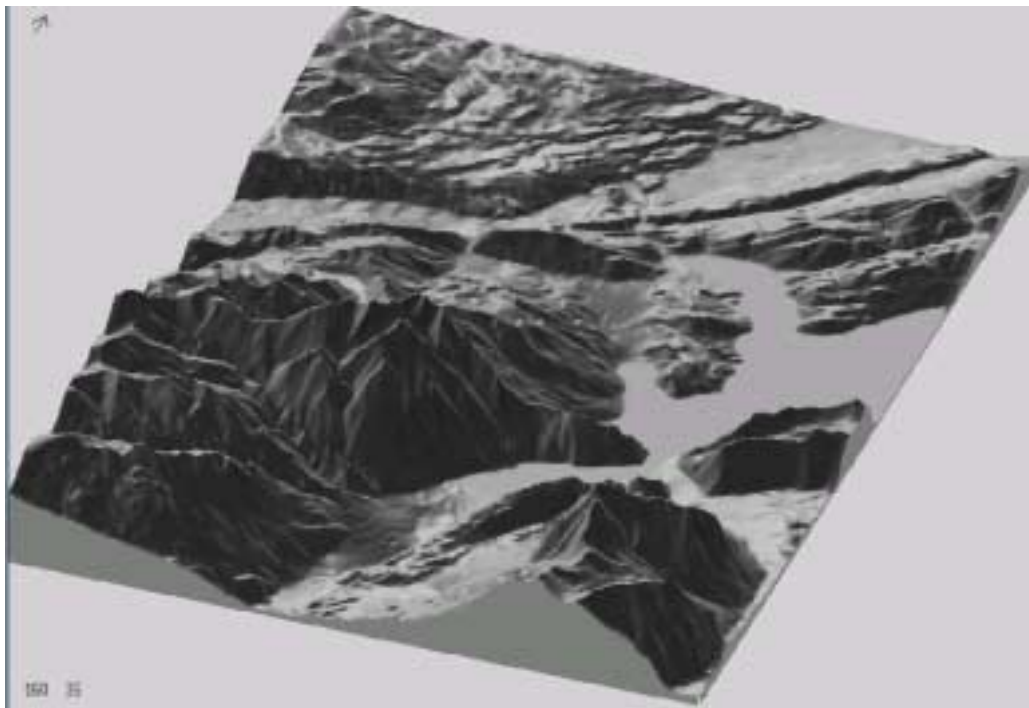
$$d = \tan v * h$$

Formula 2:
geometric displacement d depending upon height above
reference plane h and view direction V

4 Geometry of CARTERRA Geo

The geometry of geo referenced CARTERRA Geo images has been analyzed with the data set from the OEEPE-project “Topographic Mapping from High Resolution Space Sensors”. A pan-scene with a displayed pixel size of 1m, located in Switzerland was used, together with digital orthophotos and the Swiss DEM of the area for geo reference.

Figure 5: DEM of the test area in Switzerland



The nominal collection elevation of 67.66476° (nadir angle 22.33°) corresponds to an original pixel size of $0.89\text{m} \times 0.96\text{m}$, which means the resampled scene includes only a small loss of information against the original image. The tangent of the nadir angle of 0.41 shows the relation between the height difference against the reference plane and the horizontal displacement. The altitude in the mountainous region goes from 415m to 2197m above mean sea level. The DEM has a grid interval of 25m .

Control points have been measured from the digital orthophotos and the IKONOS-Geo-scene. The geo-reference of both allowed a direct handling of the coordinates of the IKONOS-scene in UTM (WGS84) and the Swiss orthophotos in the Swiss national coordinate system, an oblique Mercator system. Based on the X,Y-position in the orthophotos, the corresponding height has been interpolated in the DEM (using the Hannover program DEMINT). A bilinear interpolation of the DEM is required, because even a polynomial fitting of 2nd degree (6 unknowns) based on 3×3 points resulted in mean square discrepancies of 9.2m . The three dimensional coordinates have been transformed from the Swiss national coordinate system to UTM (Hannover program BLTRA). In the UTM-coordinate system the control points determined in the IKONOS-scene could be compared with the transformed points from the orthophotos. Of course the positions directly determined with

the CARTERRA-Geo-scene are dependent upon the height against the reference plane and also any remaining scene orientation error. The mean square of the difference of the total 128 points was: RMSE-X = $\pm 124.4\text{m}$ RMSE-Y = $\pm 40.2\text{m}$ with maximal differences in X: -421m and Y: -77m.

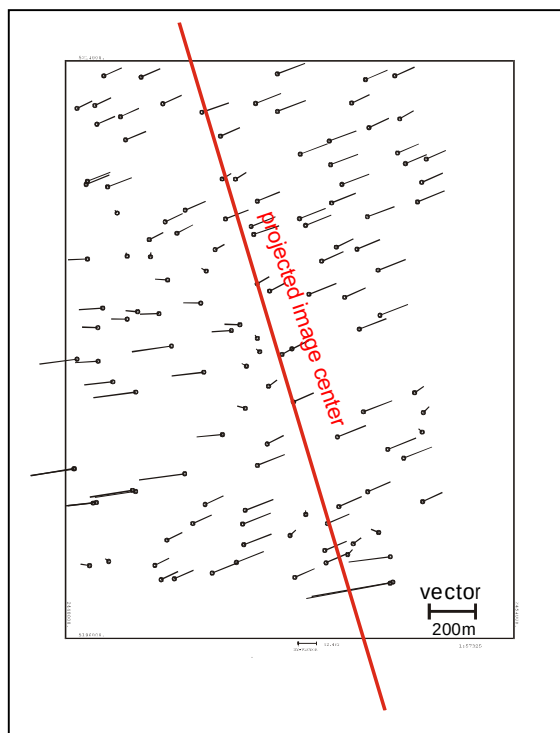


Figure 6: geometric differences CARTERRA Geo against control points

The direction of the vectors of differences is approximately the same, caused by the dominating influence of the height difference against the reference plane and a small shift and rotation of the IKONOS-scene orientation.

In figure 6 the projected image center is shown as a line approximately perpendicular to the major vector direction. The small change of the vector direction can be explained by the cumulated effect of the height influence and errors of the scene orientation. The position discrepancies up to 421m are directly dependent on the height differences against the plane of rectification and the view direction.

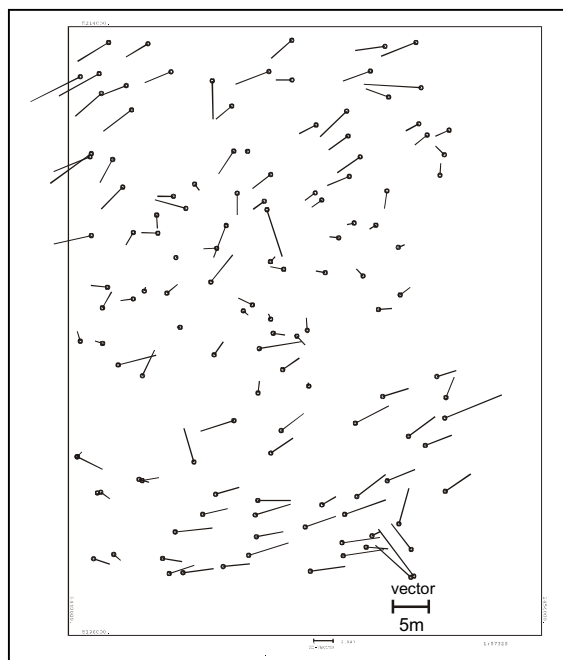


Figure 7: differences after correction by the influence of height

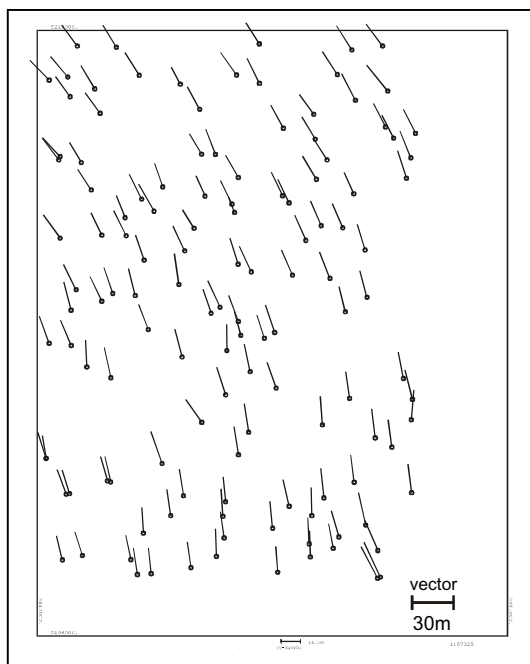


Figure 8: differences after correction by influence of height + shift in X and Y

The height level of the plane for rectification in this case is approximately 800m above mean sea level.

After correcting the influence of the height against the reference plane by the view direction against the individual nadir angle, the mean square differences have been reduced to $RMSE-X = \pm 7.5m$ and $RMSE-Y = \pm 18.5m$ (figure 7). The again very obvious systematic errors can be explained by the accuracy of the geo-reference of the IKONOS-scenes without control points. A shift correction (in X: -

6.8m, in Y: 18.3m) reduces the mean square differences to $RMSE-X = \pm 3.5m$ and $RMSE-Y = \pm 2.3m$. Again there are obvious systematic errors (figure 8) corresponding to a rotation of 0.4° , which means a shift is not sufficient - a similarity transformation has to be used.

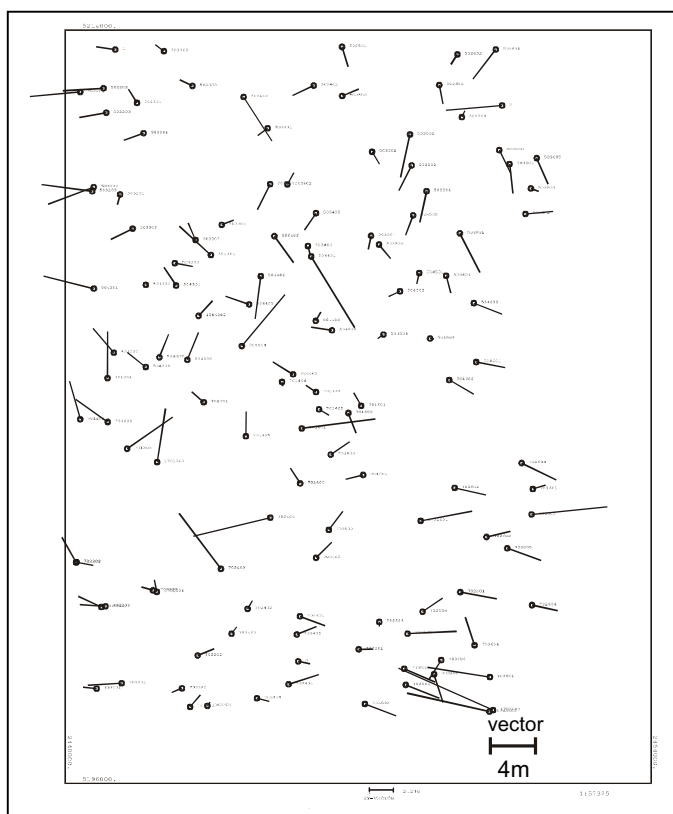


Figure 9: differences after correcting the influence of height + similarity transformation to control points

After height correction and similarity transformation to the control points the mean square differences are reduced to $\text{RMSE-X} = \pm 2.57\text{m}$ and $\text{RMSE-Y} = \pm 1.89\text{m}$ for 128 control points. These values are dependent upon the reference height used for rectification. If the reference height for the rectification does not correspond to the definition used by Space Imaging, larger discrepancies can be seen. Usually the reference height for rectification is not known and has to be estimated. This problem can be solved also by an affine transformation instead of a similarity transformation after the height correction. Based on an affine transformation, the results are independent upon the reference height for transformation and in the case of the OEEPE dataset the mean square discrepancies are reduced to $\text{RMSE-X} = \pm 2.52\text{m}$ and $\text{RMSE-Y} = \pm 1.72\text{m}$. Nevertheless there are local systematic effects shown by a covariance analysis, the relative accuracy of neighbouring points up to a distance of 1km is only $\text{RMSE-X} = \pm 1.76\text{m}$ and $\text{RMSE-Y} = \pm 1.23\text{m}$. This can be explained by the accuracy of the control points themselves, digitized from digital orthophotos – within the same orthophoto the accuracy is better than the absolute accuracy. In addition to this, a separate computation has been made using only control points which have been identified as good during the digitizing procedure. For the 79 clearly visible control points the mean square differences are $\text{RMSEX} = \pm 1.67\text{m}$ and $\text{MESY} = \pm 1.60\text{m}$ corresponding to approximately 1.6 pixels. Again we have an influence of the reference points from the orthophoto, which means the final error component coming from the geometrically improved IKONOS images is smaller, but here we are at the limit of the required accuracy. If the nominal collection elevation and azimuth are adjusted based on control points, approximately the same results are achieved, with $\text{RMSE-X} = \pm 2.56\text{m}$ and $\text{RMSE-Y} = \pm 1.65\text{m}$. These root mean square errors of X and Y are similar to those given by Space Imaging.

A common rule of thumb indicates that to map from an image, a pixel size of between 0.05 and 0.1mm in the map is required. This corresponds to a possible map scale for the panchromatic IKONOS images of between 1:10 000 and 1:20 000. For a map, the horizontal accuracy requirement is limited to $\pm 0.2\text{mm}$ or $\pm 2\text{m}$ for a map scale of 1:10 000. For this reason, no demand for a higher accuracy exists.

The results shown are based on the full set of control points used in the Hannover program CORIKON. If the nominal collection azimuth and the nominal collection elevation are available, the improvement of the Geo-scene can be made using a smaller number of control points. Based on just **4 control points**, at the 124 remaining points, root mean square differences of **$\text{RMSE-X} = \pm 2.00\text{m}$ and $\text{RMSE-Y} = \pm 1.99\text{m}$** have been reached – the root mean square of both components is just 8% more than in the case of the use of all control points.

5 Conclusion

The geometry of CARTERRA Geo-products can be upgraded without knowledge of the full scene orientation to an accuracy corresponding to the CARTERRA Precision Plus. Only a limited number of control points are required if the nominal collection azimuth and the nominal collection elevation are available. If this is not the case, control points covering the whole Z-range in the scene must be used for the determination of these values.

Oeepe – Project
on
Topographic Mapping from High Resolution Space Sensors

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Work package 3 – ‘High High Resolution Sensor Data for Automatic Change Detection’

1 Introduction

A problem for organizations that create and maintain large cartographic and geographical information system (GIS) databases is the need to update those databases sufficiently frequently. In particular, national vector 'topographic' (or feature-based) data such as Ordnance Survey (OS) Land-Line data and polygon coverages such as OS MasterMap are costly to update on a regular basis. Therefore, methods that increase the efficiency and cost-effectiveness of the database updating process are the goal of much research (e.g., Singh, 1989; Yuan and Elvidge, 1998; Mas, 1999). These methods include those designed to (i) allow automatic update and (ii) detect areas that have a high probability of having changed since the last update (allowing the targeting of certain areas for investigation and, therefore, more efficient manual update). This paper investigates the utility of some simple local methods for the latter objective: change detection.

The wide availability of fine spatial resolution satellite remote sensing (Aplin *et al.*, 1997) has brought new possibilities for change detection using remotely sensed imagery. For example, the 4 m by 4 m spatial resolution of the multispectral system (MS) onboard the IKONOS satellite far exceeds the finest spatial resolution available previously. Prior to IKONOS, the finest spatial resolution available was 20 m by 20 m, provided by the High Resolution Visible (HRV) MS onboard the Système Pour L'Observation de la Terre (SPOT) satellite. This increase in spatial resolution is important because many features of interest in remotely sensed scenes cannot be resolved sufficiently with a spatial resolution of 20 m by 20 m.

The potential value of the increase in spatial resolution described above and, therefore, the level of detail provided may be greatest for scenes that contain relatively small features: in particular, features whose size is between the two spatial resolutions above. Thus, one potential application of IKONOS MS imagery may be in detecting change in urban scenes where the features of interest may be as small as 8 m by 8 m (individual buildings). However, for that potential to be realised several problems will need to be overcome. For example, image geometric registration will need to be extremely accurate (perhaps more accurate than is currently possible, with ortho-rectification a minimum requirement). Other problems are discussed in section 5 below. In this paper, the focus is on a predominantly agricultural scene that borders an urban area in southern England.

Where the objective is change detection, the investigator needs to make some important decisions regarding the framework for the analysis. In particular, the investigator needs to decide whether the analysis will occur in attribute or geometric space (Burrough and McDonnell, 1998). In attribute space, the actual values of each pixel (raster) or each feature (vector) are compared. In geometric space, it is the locations of the boundaries of features that are compared. While comparison of attributes is straightforward (for example, subtraction using overlay), the comparison of feature boundaries in geometric space can be complex. A second choice relates to whether the raster or vector data model (or other, for example, object-oriented model) will be used. Generally, comparison in attribute space is simplest using the raster data model, while comparison in geometric space is usually undertaken with the vector data model, although in each case the converse is also possible.

Whatever the choice of space and data model for comparison, by far the most preferable choice of *data set* is always to compare like-with-like. That is, it is desirable to compare, for

example, IKONOS MS imagery for one date with IKONOS MS imagery for another date. These data should also, by default, be processed to the same units. For example, it would be sensible to compare reflectance data or to compare land cover classifications. However, it would be unwise to compare, for example, radiance values directly since radiance is a function of several variables, including illumination conditions. By definition, any differences between two images of reflectance should be due to changes in conditions in the scene of interest between the two dates. Some differences may occur due to changes in illumination, view angle and so on. However, the changes detected may be *expected* to relate to changes in the scene.

In some cases, like-with-like comparison may not be possible. For example, the only data available for the two dates of interest may be in the vector data model for the first date and in the raster data model for the second date. This is actually likely to be the case now, when the need to update digital vector databases (say from five years ago) arises, but suitable IKONOS MS images are available for only the last two years. The problem that this paper addresses is as follows: given different variable types (e.g., categorical, continuous), from very different sources (e.g., cartographic database, remotely sensed image), represented using different data models (e.g., vector, raster) is it possible to use *local* statistics to provide a sound basis for change detection.

In this paper, the objective was to attempt to detect change where the data for the first date (simulated OS MasterMap data) were in the vector data model and the data for the second date (IKONOS image with a spatial resolution of 4 m by 4 m) were in the raster data model. This objective is far more difficult to achieve than the 'like-with-like' comparison described above.

2 Methods

2.1 Classification of the raster data

The procedure proposed in this paper involves converting simulated OS MasterMap data to the raster data model. As part of this procedure, one of two vector attributes needs to be assigned to the pixels of the new raster image. First, unique identifiers may be used from the OS MasterMap data. In the simulated sample used in this study, these range in value from 1 to the number of features in the database and essentially allow each individual polygon to be delimited spatially in the new raster image. Second, 'Type' (feature) data may be used. These Type data are similar to a land *use* classification. The unique identifier or Type values may then be compared in some way to the IKONOS MS imagery.

To provide a sound basis for change detection, the raw image data need to be processed to better correspond to the unique identifiers (that is individual polygon features) or Type data *prior* to comparison. We chose to classify the imagery. Specifically, we selected two unsupervised classifiers: *k*-means and a spatial classifier based on Adaptive Bayesian clustering (ABC). The *k*-means classifier is well known and so only the Adaptive Bayesian clustering algorithm is described here.

2.2 Adaptive Bayesian clustering

Adaptive Bayesian clustering (Ashton 1998) maximises the probabilistic model

$$P(k | v) \propto P(v | k)P(k) \quad (1)$$

for all clusters, k , where v are the observed data.

$P(v | k)$ is determined by making two assumptions. The first is that pixel values belong to a multivariate Gaussian distribution in spectral space. The second is that the mean and standard deviation of this distribution are slowly varying over space. The $P(v | k)$ term is therefore calculated for each pixel within a region local to that pixel. $P(k)$ is determined by using a Gibbs random field (Geman and Geman 1984) as a global model of the distribution of clusters in the image. The functional form of this is calculated by subtracting a weighted sum of pixels adjacent to the current pixel that belong to the same cluster as the current pixel from the weighted sum of pixels that belong to a different cluster. As such, $P(k)$ requires only the current cluster distribution and no spectral information. In this way, the $P(v | k)$ term provides the spectral information and the $P(k)$ term provides the spatial information to the calculation of $P(k | v)$. The weighting of the sums of adjacent pixels in the $P(k)$ term defines the bias towards spatial information in the calculation.

The process by which clustering is achieved is iterative. It begins with an initial estimation of cluster locations using an algorithm such as k -means (Hartigan and Wong 1979) (which uses spectral information only). The local region within which the $P(v | k)$ term is calculated is initially set to the size of the image. The means and standard deviations are calculated within the local region. When the local region is the size of the image, this results in only one calculation of these values. However, when the region size is reduced in later iterations, the calculation of local means and standard deviations is performed only for pixels at intervals in the image and interpolated for the remaining pixels. Each pixel is then assigned to the cluster, k_i , for which $P(k | v)$ is maximised and the global probability (the sum of the maximum $P(k | v)$ s for all pixels) calculated. While the global probability is increasing, only the regional means are calculated before pixels are assigned to their maximum probability cluster. When the global probability stops increasing, the size of the local region is reduced. The means and standard deviations are calculated for the smaller region and then pixel assignment continues. The whole process stops when a minimum region size is reached.

2.3 Local Differencing

Once the IKONOS MS imagery was classified, comparison with the OS vector data was possible. However, the main problem was in comparing data that were represented in different units (for example, unique identifiers compared to land cover class). To facilitate comparison, local statistics were used, the idea being that within a small local window or kernel categorical attribute representations can be reduced to either binary or close-to-binary representations. These binary representations can then be compared, irrespective of the complexity of the categorical representation for the whole scene or image.

Binary difference

For a moving $(2w+1$ by $2w+1)$ window centred on pixel (m,n) applied to an image of M rows by N columns, the binary difference $\hat{d}_{mn}$ between variables z and y is calculated as:

$$\hat{d}_{mn} = \min_{ij} \left[\sum_{i=m-w}^{m+w} \sum_{j=n-w}^{n+w} \sum_{k=m-w}^{m+w} \sum_{l=n-w}^{n+w} |I(z_{i,j} = z_{k,l}) - I(y_{i,j} = y_{k,l})| \right] \quad (2)$$

where, w is set to 1, but it is assumed that w decreases to zero at the boundary of the image and I represents the indicator function (i.e., takes the value 1 if true, 0 if false). Thus, each pixel (k, l) within the window is used in turn to determine the 'current' class. Then all pixels (i, j) are assigned to an indicator variable taking the value 1 (if the same class as for $z_{k,l}$) or 0 (if a different class) for each pixel (k, l) (i.e., via $I(z_{i,j} = z_{k,l})$). This is applied to both z and y data sets (two dates). The differences between the indicators $I(z_{i,j} = z_{k,l})$ and $I(y_{i,j} = y_{k,l})$ at all locations (i, j) within the window, for all classes $z_{k,l}$ within the window are then summed via Equation 2. The value $\hat{d}_{mn}$ is, thus, the sum of all the differences for a single pixel location (m, n) .

2.3.1 Difference of variances

The local variance σ_w^2 may be predicted for a moving $(2w+1$ by $2w+1)$ window applied to an image of M rows by N columns using:

$$\hat{\sigma}_{mn}^2 = \frac{1}{(2w+1)^2} \sum_{i=m-w}^{m+w} \sum_{j=n-w}^{n+w} [\bar{z}_{m+i,n+j} - z_{m+i,n+j}]^2 \quad (3)$$

where, w is set to 1, but it is assumed that w decreases to zero at the boundary of the image. To account for categorical data, the algorithm was modified as follows:

$$\hat{\sigma}_{mn}^2 = p_{mn} \cdot q_{mn} \cdot k_{mn} \quad (4)$$

where,

$$p_{mn} = \frac{\sum_{i=m-w}^{m+w} \sum_{j=n-w}^{n+w} I(z_{m+i,n+j} = z_1)}{\sum_{i=m-w}^{m+w} \sum_{j=n-w}^{n+w} I(z_{m+i,n+j} = z_1) + \sum_{i=m-w}^{m+w} \sum_{j=n-w}^{n+w} I(z_{m+i,n+j} = z_2)} \quad (5)$$

where z_1 is the mode (i.e., the class that occupies the largest number of pixels) and z_2 is the class that occupies the next largest area (that is, p_{mn} is calculated as the proportion of the area covered by the modal class and the next largest class combined that belongs to the modal class),

$$q_{mn} = \frac{\sum_{i=m-w}^{m+w} \sum_{j=n-w}^{n+w} I(z_{m+i,n+j} = z_2)}{\sum_{i=m-w}^{m+w} \sum_{j=n-w}^{n+w} I(z_{m+i,n+j} = z_1) + \sum_{i=m-w}^{m+w} \sum_{j=n-w}^{n+w} I(z_{m+i,n+j} = z_2)} \quad (6)$$

and k_{mn} is a factor that scales the variance to lie in the range (0, 1).

3 Study site and data

3.1 OS vector data

As OS MasterMap data were still under development at the time of undertaking the research in this report, the OS supplied a pre-cursor to this data, based on the specification for a Digital National Framework (DNF). The data was obtained by manipulation of the OS TOPO96 product, that had not yet been subjected to the final quality improvement flowline. The underlying concept and data that comprise DNF are described in OS consultation paper1/2000 (OS, 2000a) and a family of related consultation papers available from the OS DNF web site (OS, 2000b) (Harrison *et al.*, 2001). DNF data are created through a restructuring of the National Topographic Database to provide a seamless database of topographic features (Harrison *et al.*, 2001).

The OS vector data set used in the analysis was a simulated OS DNF tile (number 4919) of a part of Fair Oak, a small, predominantly residential area north of Southampton in Hampshire (Figure 1). This data set was used to provide the most basic feature information as represented in the geometry of the features (and labelled by their unique identifier codes) and Type (feature) codes. It should be noted that these feature codes represent land *use* and not land cover as might be predicted from a remotely sensed image.

Figure 1 shows how several features were altered in the vector data providing a test for the IKONOS MS imagery and the algorithms proposed. The changes are (1) a field boundary was altered, (2) a field boundary was added, (3) an enclosed polygon was added, (4) the feature Type within a field was changed and (5) a field boundary was removed from between two fields of the same land cover type.

3.2 IKONOS MS imagery

An IKONOS MS image of the whole of Chandler's Ford and Eastleigh, north of Southampton in Hampshire was acquired on 30th August 2000. The swath width of the IKONOS MS sensor is 11 km such that the imagery covered an area of 11 km by 11 km. A part of this image (covering the same area in Fair Oak as the OS vector data) is shown in Figure 2. The image was provided in four wavebands (blue, 0.45-0.52 μm , Figure 2a; green, 0.52-0.6 μm , Figure 2b; red, 0.63-0.69 μm , Figure 2c; near-infrared, 0.76-0.9 μm , Figure 2d).

4 Analysis

4.1 Geometric rectification

Prior to geometric rectification, the imagery was compared to a pixel-map of the study area. 107 points in the IKONOS MS image were compared with their counterparts in an OS Landplan image. The average difference was 13.9 m with a minimum of 0.3 m and a maximum of 52.4 m. Given these large errors, geometric rectification was undertaken based on 45 ground control points (GCPs).



Figure 1. OS simulated DNF data showing altered features as follows: (1) Added curved boundary (double line), (2) Added curved boundary (single line), (3) Added enclosed polygon, (4) Altered land cover class and (5) removed field boundary (existed previously where the 5 is placed presently).

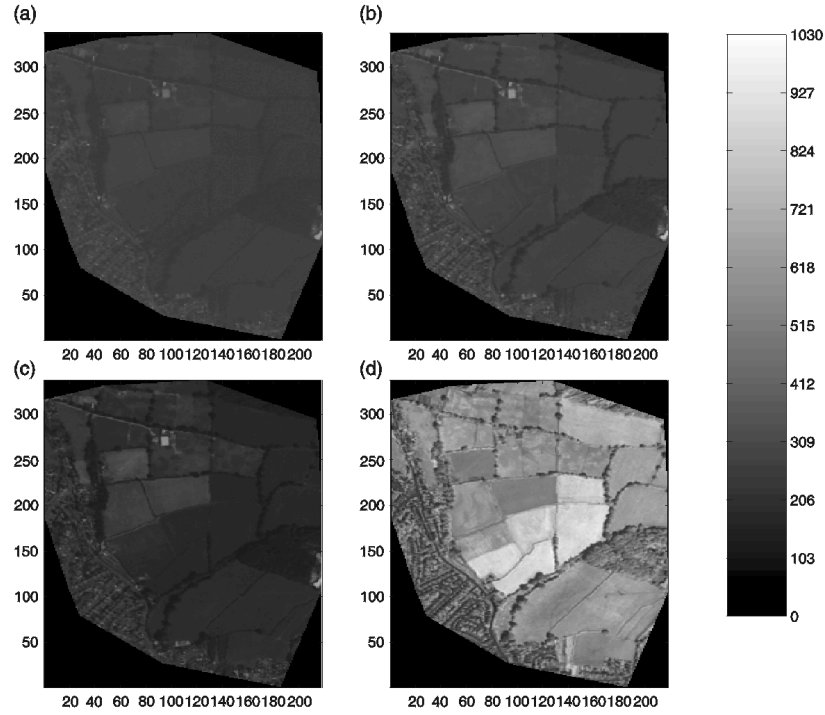


Figure 2. IKONOS MS imagery of Fair Oak, Eastleigh, Hampshire. (a) blue, 0.45-0.52 μm , (b) green, 0.52-0.6 μm , (c) red, 0.63-0.69 μm and (d) near-infrared, 0.76-0.9 μm .

4.2 Image classification

A lack of detailed ground data prevented the use of supervised classification algorithms in this case. The k -means clustering algorithm was applied to the IKONOS MS image of Fair Oak producing 20 clusters. A large number of classes was chosen to reflect the complexity of the IKONOS MS image. For example, in urban areas a variety of land covers were present including roof-tiles, asphalt, concrete, vehicles, grassland, woodland, bare soil and water. Each of these was complicated by the effects of varying illumination conditions and shadow (especially for roof-tiles and garden boundaries such as fencing, hedging and walls). These clusters were subsequently grouped into 3 classes representing predominantly (i) woodland, (ii) grassland and (iii) built land (Figure 3a). The spatial distribution of these classes was deemed to represent much of the boundary information of interest in the predominantly agricultural scene.

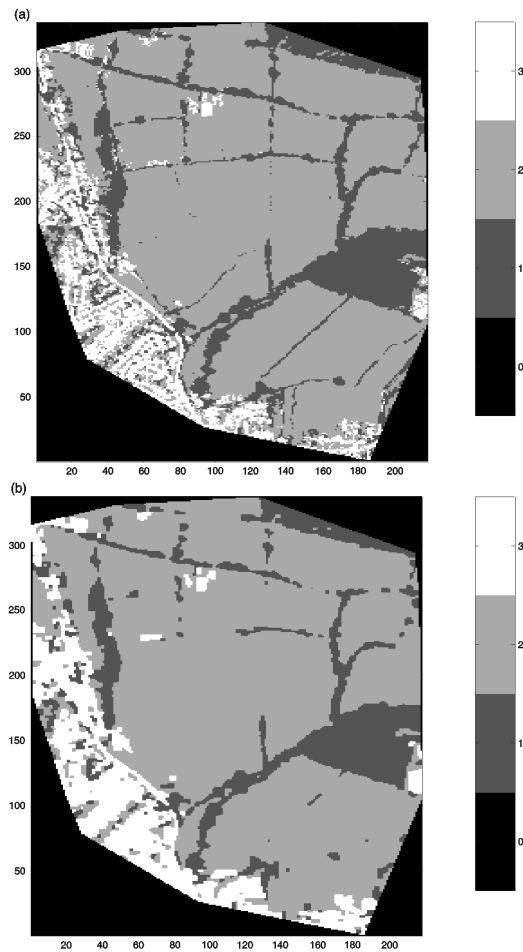


Figure 3. (a) *k*-means classification of the IKONOS MS image, (b) Adaptive Bayesian classification of the IKONOS MS image (class 1 is woodland, class 2 is grassland and class 3 is built land).

The Bayes ABC classifier was applied to the IKONOS MS image using the 3 clusters provided by the *k*-means classification as a starting point. The result is shown in Figure 3b. The effect of the ABC classifier was to smooth the classification. Notably, much of the detail in the urban area has been smoothed out leaving just the built land class where previously built land was combined with grassland (that is, gardens). Further, certain hedgerows and boundaries comprising lines of trees have been broken up (most notably the thin lines of 'woodland' to the south of the image).

4.3 Local Differencing

4.3.1 Unique identifier

Figure 4a shows the local binary difference between the k -means classification and the unique identifier raster image. Figure 4b shows the local binary difference between the ABC classification and the unique identifier raster image. There appears to be very little difference between them. In both cases, 'altered features' 1, 2, 3 and 4 have been detected. However, there appears to be a very high false alarm rate.

The largest difference (between the classifiers) is for the urban area where the smoothing effect of the ABC classifier has caused large differences (between the data for the two dates). Essentially, the building features are distinguished in the rasterized vector data and, therefore, need also to be so in the classified IKONOS imagery. For the ABC classifier this is not the case. This result is as expected. The smoothing effect of the ABC algorithm has led to an effective increase in pixel size and, given that the differencing (between dates) already occurs within a window of 3 by 3 pixels, the spatial resolution is insufficient to resolve individual buildings and similar features in urban areas. Therefore, if the objective is

to detect change within urban areas, the ABC classifier will probably be of little value.

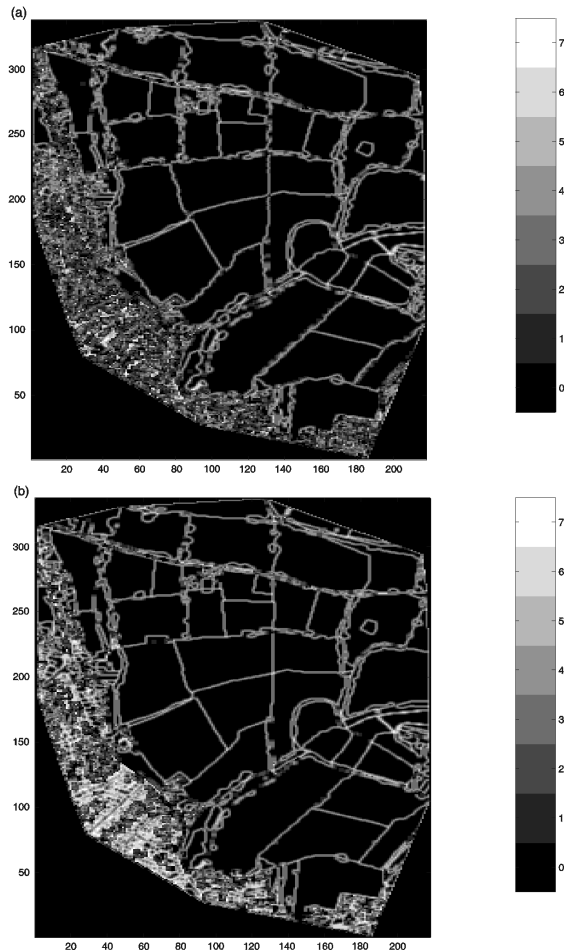


Figure 4. Local binary difference between (a) the k -means classification and the unique identifier data and (b) the adaptive Bayesian classification and the unique identifier data.

4.3.2 Type

Figure 5a shows the local binary difference between the k -means classification and the polygon Type raster image. Figure 5b shows the local binary difference between the ABC classification and the polygon Type raster image. Again, differencing based on both classifications has managed to identify the main 'altered features'. However, although the false alarm rate is still high, it is much lower than for the unique identifier data (section 4.2.1 above).

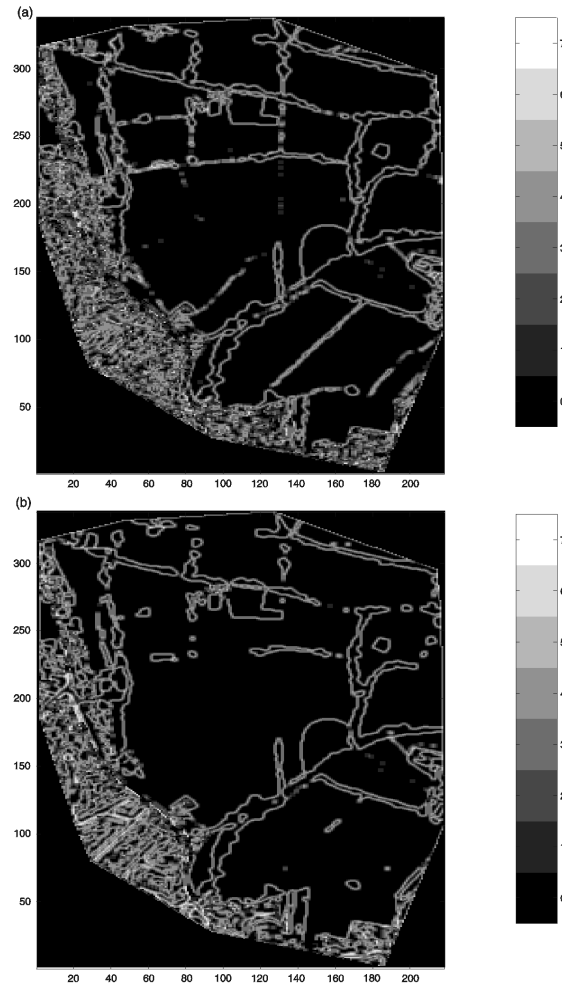


Figure 5. Local binary difference between (a) the k -means classification and the Type data and (b) the adaptive Bayesian classification and the Type data.

It is notable that in the agricultural region, the Bayes ABC classifier has a lower false alarm rate than the k -means classifier. This is a function of the smoothing effect of the ABC classifier which removed many of the small-scale features. Both classifiers provide

potentially useful, albeit slightly different, information in relation to the original Type data. In particular, the woodland that separates many of the agricultural fields is not represented well in the Type data, but is represented in the classifications. The ABC classifier has helped to reduce the area of such woodland, leaving perhaps the most important boundary information. Certainly, such information could be of value to the Ordnance Survey, depending on the scale of the mapping and the level of generalisation desired in the classification system.

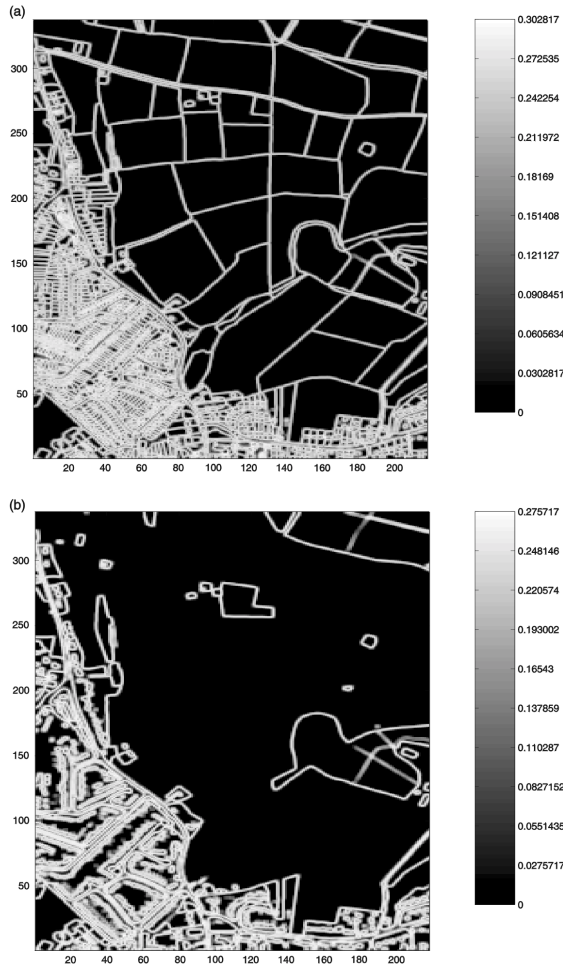


Figure 6. Local (thematic) variance predicted for (a) the unique identifier data and (b) the Type data.

4.4 Difference of variances

Figures 6a and b show the local (thematic) variance predicted for the unique identifier data (Figure 6a) and the Type data (Figure 6b). Both local variance images were computed from the 1 m by 1 m pixel rasterized vector data within a window of 12 pixel by 12 pixels (that is, equivalent to a 3 by 3 pixel window applied to 4 m by 4 m pixels). The differences between the unique identifier and Type data sets are clear. In the urban area, the unique identifier local variance has preserved much spatial detail relating to individual houses and roads. For the Type data the buildings are not apparent. For the agricultural area, the unique identifier local variance has preserved the field boundaries, but the Type local variance has not. Thus, importantly, while the 'altered features' (1, 3 and 4) are apparent in both data sets they are much more striking in the Type data because there is little other information in the surrounding area.

Figures 7a and b show the local (thematic) variance applied to the k -means classification (Figure 7a) and the ABC classification (Figure 7b). For the agricultural area, the local variances are as might be expected given the classified images shown in Figure 3. However, for the urban area there is an important difference between the two local variances: the smoothing effect of the ABC classifier has removed a lot of the local variance. Unfortunately, although this leads to a cleaner looking image, this detailed local variation is necessary for comparison with the rasterized OS vector data.

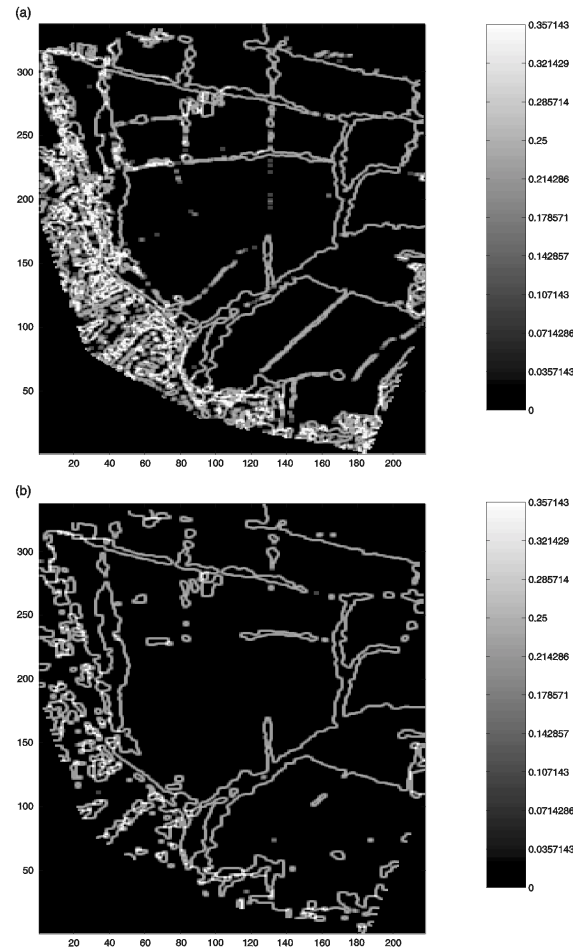


Figure 7. Local (thematic) variance predicted for (a) the k -means classification and (b) the adaptive Bayesian classification.

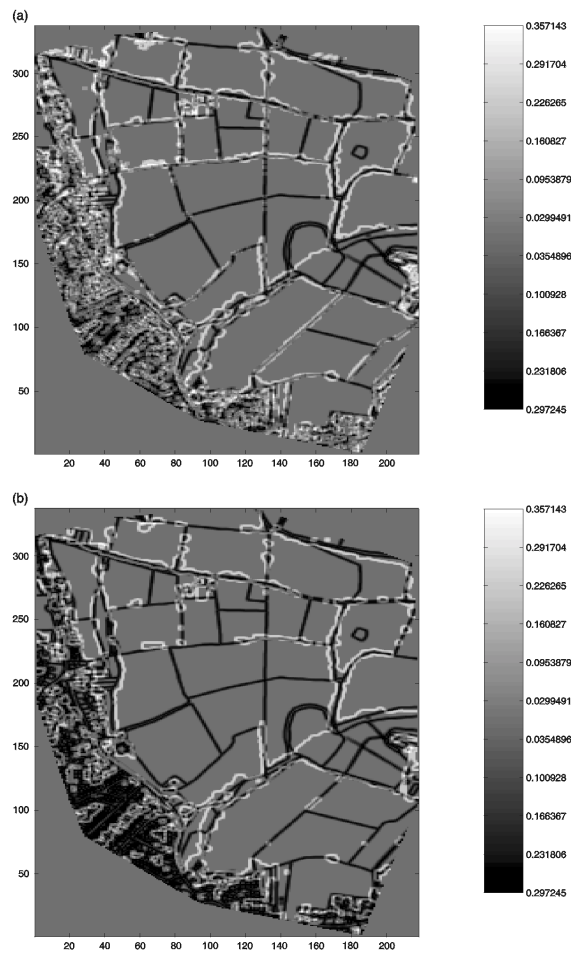


Figure 8. Local difference between the local variances of (a) the k -means classification and the unique identifier data and (b) the adaptive Bayesian classification and the unique identifier data.

4.4.1 Unique identifier

The difference between the local variance of the k -means classification and the local variance of the unique identifier image is shown in Figure 8a. The local difference between the local variance of the Bayes ABC classification and the local variance of the unique identifier image is shown in Figure 8b. In both cases, the positive differences have been shown in white while the negative differences have been shown in black. Since the positive and negative differences correspond very little spatially, both white and black lines appear adjacent to one another in most cases, displaying simultaneously the variances in both the rasterized vector and classified remotely sensed data.

For the urban area, for both the k -means and the ABC classifications, the algorithm seems to predict large areas of both positive and negative change. In particular, for the ABC classification large areas of negative change are depicted. This is clearly erroneous and it may be concluded that the present analysis based on IKONOS imagery and the differencing of local variances computed within a 3 by 3 window is insufficient to detect change in urban areas.

For the agricultural area, the reason that the black and white lines do not correspond is because the white lines (classified IKONOS data) correspond mainly to the differences between woodland (physical field boundaries) and grassland, whereas the black lines (vector data) correspond to the differences between neighbouring polygons (because the physical boundaries are not represented in the data). That is, the white lines occur on both sides of the woodland whereas the black lines occur only once, and hence black and white lines do not correspond spatially.

The above issue undermines the present attempt to use classified IKONOS imagery in relation to rasterized OS vector data to detect change in agricultural regions. Nevertheless, there are several important lessons to be learnt from the analysis and these are presented now. First, the 'altered features' (1, 2, 3 and 4) have been detected as black lines, without 'contamination' from white lines. The problem is, of course, that there are many other black lines without adjacent white lines. These black (without white) lines occur because the land cover in adjacent fields is the same, and there is no woodland or hedgerow boundary to separate the fields in the classified image. This is a fundamental problem for automatic change detection using IKONOS MS imagery. If separate fields appear homogeneous spatially and are classified into the same land cover then the local differencing algorithm cannot help but detect negative change (the field boundaries have disappeared).

The white lines in Figures 8a and b provide useful information on the presence of woodland and other physical boundaries in the British landscape (Forestry Commission, 1998). Such information, when displayed in relation to the black lines representing field boundaries is easier to interpret than when displayed alone (Figure 7). It is likely that the pattern of field boundaries found for this small area in Hampshire may be repeated for other areas of the UK. For similar areas the utility of the technique will be in mapping the (physical) land cover features 'missing' from the current OS vector database. For other areas where fields are not separated by woodland or thick hedging, the utility of the technique will depend ultimately on whether the land cover in adjacent fields is of the same class.

4.4.2 Type

The difference between the local variance of the k -means classification and the local variance of the Type image is shown in Figure 9a. The local difference between the local variance of the Bayes ABC classification and the local variance of the Type image is shown in Figure 9b.

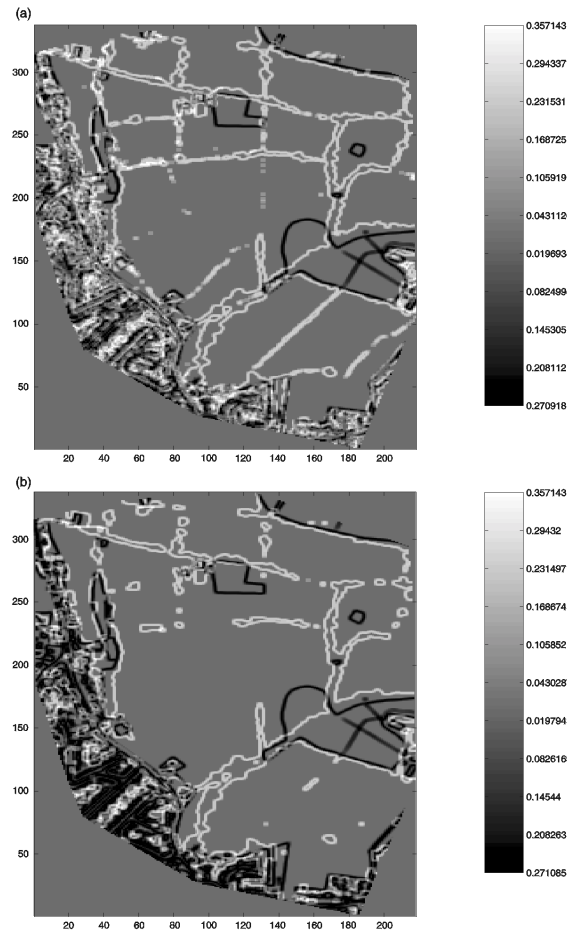


Figure 9. Local difference between the local variances of (a) the k -means classification and the Type data and (b) the adaptive Bayesian classification and the Type data.

The white and black lines have the same meaning as for Figure 8. Focusing on the agricultural area, the 'altered features' are now readily apparent because the field boundaries are not represented in the Type data. Thus, for both the k -means and the ABC classification the information displayed in Figure 9 (at least for the agricultural area) could almost all be attributable to real change. The black lines correspond to the 'altered features' while the white lines correspond to woodland areas (that is, including thick hedging) that are not represented in the OS vector data. Of the two classifiers, the simple k -means appears to have provided the greater amount of useful information. However, if only the larger woodland features are of interest, the effect of the Bayes ABC classifier may be to usefully filter out unwanted smaller features (such as hedging rather than woodland).

5 Discussion

5.1 Geometric registration

As the spatial resolution increases, so too does the requirement for precision in the geometric rectification of the data (both vector data and remotely sensed image). This is especially the case where two data sets are to be compared for the purpose of change detection. Further, the requirement for geometric precision for change detection is likely to be greater in urban areas than in agricultural areas. Geometric imprecision is likely to be one of the sources of error that led to the lack of useful change information for urban areas in Fair Oak.

Clearly, a geometric root mean square error of ± 0.5 pixel is difficult to achieve, but it is likely to be harder to achieve with IKONOS MS 4 m by 4 m pixels than with SPOT HRV 20 m by 20 m pixels. One of the reasons for this is the limit to the precision of the data used for geometric rectification (in the present case, simulated OS DNF data).

In this paper, the IKONOS MS imagery was geometrically rectified to the OS DNF data using a small set of ground control points. Given the internal consistency of satellite sensor imagery (that is, satellite sensor imagery is not subject to the roll, pitch and yaw distortions of airborne imagery), the lack of relief in the area and the small area covered by the image, this procedure was deemed sufficient for the present purpose. However, for larger areas with greater relief, this procedure would almost certainly be inadequate.

5.2 Scale

One of the most important decisions for change detection analysis is the choice of size of support (the size, geometry and orientation of the space over which an observation is defined) for comparison of the data for the two dates. The spatial resolution of the IKONOS MS sensor was 4 m by 4 m. However, the actual comparison was not made on this support. In this paper, the comparison was made within a support of 12 m by 12 m, that is, within a moving window of 3 pixels by 3 pixels. This support was used for both the binary difference and the prediction of local variances.

The choice of support provides an important limit to the potential of the change detection analysis. Importantly, the support must be considered in relation to the size of the objects of interest within the scene (Strahler *et al.*, 1986; Woodcock and Strahler, 1987; Quattrochi and Goodchild, 1997; Curran and Atkinson, 1999). For agricultural areas, the agricultural fields are of prime interest (although in this paper it was found that the boundaries may also be the subject of interest). These parcels of land are much larger than 4 m by 4 m, 12 m by 12 m and even 20 m by 20 m such that it is likely that only one boundary at a time will fall within the moving window. For urban areas, this is not the case. The objects of interest may be as small as 8 m by 8 m (small buildings). Then, change detection may be hampered by the support size of 12 m by 12 m.

5.3 Land cover classification

By far the most important limit to the change detection analysis presented in this paper was the inability to represent the features found in the OS DNF data with remotely sensed imagery. There were several problems and these are described below.

5.3.1 Illumination and shadow

First, for urban areas, variation in the azimuth angle of illumination in relation to the azimuth angle of the building roof, and the presence of shadow, limited the ability of the k -means and, subsequently, ABC classifiers to predict accurately the features of interest. Roof-tiles, which were constructed from a range of materials, ranged from very dark to very bright surfaces as a function of illumination azimuth angle in relation to the orientation of the building. Further, shadow on the lee-side of buildings added to the complexity of the scene. This complexity (within-class variation) for a single class prohibited the use of simple supervised classification algorithms (such as the maximum likelihood classifier) to predict individual features such as buildings. For this reason, and because of a lack of adequate ground data, we chose to use an unsupervised classifier to predict many (20) classes and subsequently group these classes into three simple 'primitive' classes. However, there is an important lesson here for anyone who wishes to use IKONOS 4 m by 4 m imagery to predict individual houses (and similar small features) within urban areas. While some success has been achieved by combining OS Land-Line data with IKONOS MS imagery (Aplin and Atkinson, 2001), the problems of variation in illumination conditions and shadow may make analysis based on the imagery alone inadequate.

5.3.2 Hard classification

In this paper, hard unsupervised k -means classification was used to represent the major land cover features of interest. This choice was made to facilitate the prediction of local differences and variances based on the reduction of thematic or categorical data to binary data within local windows. However, such a choice means that some information provided by the classifier has effectively been discarded. The k -means classifier allocates the pixel in question to the class or cluster to which it is nearest in feature space. However, the distances in feature space between the pixel and the class means can provide useful information on the class composition of the pixel (Foody and Cox, 1994; Atkinson *et al.*, 1997). For example, soft classification can be performed to predict the proportional membership of a pixel to each class (that is, the proportion of the pixel covered by each class). Such information is likely to be extremely important in urban areas where the features are often only slightly larger than the pixel.

An obvious extension of the research presented in this paper is to use the class proportions, as predicted using a soft classifier, to predict per-pixel variances. The same could be done for the 1 m by 1 m vector data within a 4 m by 4 m window facilitating comparison of variances on a 4 m by 4 m basis. This is likely to be far preferable to a window of 12 m by 12 m for urban areas.

6 Conclusion

The objective of this paper was to investigate the utility of IKONOS MS imagery for change detection in relation to OS DNF data. It was acknowledged at the outset that comparison of data on a like-with-like basis is the preferred route. The analysis presented in this paper was, therefore, less focused on the obvious practical question (can IKONOS MS imagery be used to fulfil the requirements of organizations such as the OS?) since the recommended route is to compare two IKONOS MS images for different dates. Having said that, there may very well arise situations in which images for two dates are not available, so the question being addressed is not vacuous. Nevertheless, the focus of this paper was more on the general question: 'can local statistics be used to provide a sound basis for comparing data represented in different ways?' (e.g., continuous v. categorical, cartographic v. image, raster v. vector).

We have demonstrated that it is possible to undertake change detection analysis for agricultural areas using IKONOS MS imagery and OS DNF data. The 'altered features' were detected in all cases, although there was a high false alarm rate also. This false alarm rate was smaller for the Type data than for the unique identifier data, as one might expect. However, despite this degree of success, major problems were also identified:

Woodland boundaries

For the particular data sets analysed, many of the field boundaries simply did not coincide, not because of real change in the scene, but because the OS DNF data did not contain the woodland and hedgerow field boundaries (real physical objects with non-zero size) that were evident in the IKONOS MS image. If such objects are of interest to a mapping organization (or any other organization, for example, a forestry service) then the method presented may have real practical value. However, if these features are of no interest, as arguably for the present objective, then they have nuisance value only.

Same adjacent land cover class

Where adjacent agricultural fields were of the same land cover class, and no physical boundary existed between them, boundaries evident in the OS DNF data were not identified by the land cover classification. This situation arose commonly in the scene analysed in this paper because most fields were grassland. This situation may be different for other areas of the UK (for example, East Anglia where crop rotation systems are in place). However, the problem will rarely vanish. Some adjacent fields will be of the same class leading to a false alarm in the change detection analysis. Again, the solution is simply to compare like-with-like.

Misregistration

Accurate geometric registration of the imagery is likely to be one of the most important requirements for change detection analysis. For the small, relatively flat area analysed in this paper simple geometric transformation of the image based on GCPs was considered sufficient for agricultural areas. However, for urban areas, this may have been inadequate. Display of the rectified image with the OS DNF data simultaneously revealed small errors in certain locations of around 0.5 pixels which will have affected the land cover classification considerably given the high spatial frequency of urban areas.

Scale of analysis

It is important to select the right scale for the analysis. In this paper, windows of 12 m by 12 m were used as the basis for comparison. While this was a suitable choice for agricultural areas, it is certainly too large for urban areas. A possible way forward was identified for urban areas: to use the land cover proportions from a soft classifier to predict variances for individual pixels facilitating comparison on a pixel-by-pixel basis.

Land cover classification

The problems introduced by varying illumination conditions and shadow undermined the land cover classification for urban areas. These problems represent serious limitations to the use of IKONOS MS imagery in urban areas. Solutions based on per-parcel analysis (Aplin and Atkinson, 2001) are possible, although they would be useless for change detection in the current context since the parcels would be provided by the OS DNF data with which comparison is desired.

In summary, it is recommended that investigators attempt to compare like-with-like. If that is not possible, then every care will need to be taken to ensure that the data are sufficiently pre-processed prior to change detection analysis to guarantee that the 'changes' detected relate to real changes in the scene and not to differences in the *representations* of the scene.

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(Note: references for all the annexes are included in the references of the main report.)

OEEPE – Project

Topographic Mapping from High Resolution Space Sensors

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Work package 4 – ‘Automatic Land Use Classification’

1 Introduction

The recent availability of very high spatial resolution satellite sensor imagery (Aplin *et al.*, 1997) has opened new opportunities for the remote sensing of land cover and land use. The widely available IKONOS multispectral (MS) imagery has a spatial resolution of 4 m by 4 m. Prior to IKONOS, the finest spatial resolution available for multispectral imagery was 20 m by 20 m, provided by the High Resolution Visible (HRV) sensor on-board the French Système Pour L'Observation de la Terre (SPOT) satellite. This change represents an important increase in the spatial resolving power of satellite remote sensing. It means that greater *spatial information* is provided in the IKONOS MS imagery. It is this increase in spatial information that is of potential use in classifying land cover and, thereafter, land use. However, to harness the potential spatial information provided by satellite sensors such as IKONOS MS two problems must first be overcome. These two issues form the basis of this introduction.

1.1 Land cover and land use

It is important to realise that remotely sensed imagery provides information on land cover, not land use. Land cover is (as the name implies) the *material* on the surface of the Earth. Land use, on the other hand, involves *function* (i.e., what the land is being used for by humans). Clearly, the reflectance recorded from the surface of the Earth will be a function of land cover, but not land use. This means that any study with the objective of predicting land use must employ a two-stage strategy where, first, remotely sensed imagery is used to predict land cover and, second, the predicted land cover map is used, together with spatial texture or context, to predict land use. For example, if a small area of rooftiles is surrounded by vegetation (land cover), it is likely that the rooftiles cover a house surrounded by its garden (land use).

A second-order analysis to predict land use may be achieved either (i) by operation on the classified raster imagery with spatial kernels (moving windows) (i.e., textural analysis, e.g., Carr, 1996) or (ii) by transformation of the raster into an object-based representation with subsequent contextual analysis (e.g., Barr and Barnsley, 1999). Unfortunately, whereas the prediction of land cover (first-order variable) from remotely sensed imagery is relatively straightforward, prediction of land use (second-order variable) based on texture or context is notoriously difficult (Barr and Barnsley, 1999). This has important implications for the present research.

1.2 Classification accuracy

Classification accuracy is often inversely related to spatial resolution (Townshend, 1992). Thus, the use of imagery with small pixels (e.g., IKONOS MS) can result in a lower classification accuracy than imagery with large pixels (e.g., SPOT HRV). One of the main reasons for this loss of accuracy with an increase in spatial resolution is the introduction of within-parcel variance into the classification. That is, when pixels are small, detail that is of no interest may be resolved leading to inaccurate classification. Of course, the relation only holds for a given level of spatial generalisation. Thus, the classification of patches *within* a cereal field into bare soil (which are in fact bare soil) will be regarded as misclassification if the investigator wishes the whole field to be classified as cereal. However, this is a direct

result of the level of spatial generalisation desired (selected) by the investigator, rather than 'real' misclassification.

In response to the above problem several researchers (e.g., Smith *et al.*, 1998; Aplin *et al.*, 1999; Aplin and Atkinson, 2001) have suggested that IKONOS MS imagery should be combined with per-parcel classification, whereby available vector data (delineating the boundaries between fields and other objects) may be used to group pixels for subsequent analysis. The main advantage of analysing pixels on a per-parcel basis is that the objects of interest (e.g., agricultural fields, woodland areas, water bodies etc.) are assigned to a *single* class, removing the problem caused by within-parcel variance. A further advantage of such a per-parcel approach is that all the pixels within a given parcel are available for analysis as an ensemble, allowing the statistical distributions of pixels per-parcel to be analysed (rather than pixels in isolation).

The main disadvantage of per-parcel classification is that if for any reason the classification is incorrect, the whole parcel will be incorrect rather than just a few pixels. A commonly reported reason for inaccuracy in per-parcel classification is error in the vector data. For example, if a field boundary is missing, misclassification of an entire field may arise (Aplin *et al.*, 1999). Per-parcel classification will be demonstrated in this paper.

1.3 Objective

Two sets of data were made available for this research: (i) IKONOS MS imagery of Chandler's Ford Hampshire acquired on 30 August 2000 and (ii) simulated OS Digital National Framework (DNF) polygon data of the same area. The objective was to classify land use for a part of the area given these two data sets. For convenience, the European Union CORINE classification system was chosen making the objective to predict CORINE land use classes for a part of Chandler's Ford (with the eventual aim of predicting CORINE land use for the whole UK).

For the reasons given in section 1.2 it should be clear that a sensible approach would be to use the IKONOS MS and DNF data to predict, initially, land cover on a per-parcel basis, thereafter attempting to convert land cover to land use based on texture or context. However, it was clear from the start that there was only academic interest in such an approach because most of the land use information to be predicted could be obtained accurately from the DNF data itself. More generally, where per-parcel analysis is to be undertaken with IKONOS MS imagery to predict land use, it is likely that much of the information of interest may be obtained from the vector data directly. For example, even where the vector data is not attributed (as was DNF) the size, shape, orientation and context of the objects represented contains probably more information on land use than the IKONOS imagery itself (which is actually related directly to land cover, not land use).

The objective of the present research was two-fold: (i) to determine the CORINE land use information that might be predicted directly with DNF data and (ii) to demonstrate the utility of per-parcel classification of IKONOS MS imagery (for predicting those parts of CORINE that could not be predicted using DNF).

2 Data

2.1 Characteristics of IKONOS imagery

An IKONOS MS image of the whole of Chandler's Ford and Eastleigh, north of Southampton in Hampshire was acquired on 30th August 2000. The IKONOS MS sensor has a spatial resolution of 4 m by 4 m (Aplin *et al.*, 1997). The swath width of the IKONOS MS sensor is 11 km such that the imagery covered an area of 11 km by 11 km. The imagery was provided in four wavebands (blue, 0.45-0.52 μm ; green, 0.52-0.6 μm ; red, 0.63-0.69 μm ; near-infrared, 0.76-0.9 μm).

2.2 DNF polygon data

As OS MasterMap polygon data were still under development at the time of this research, the Ordnance Survey supplied a pre-cursor to this data, based on the specification for a Digital National Framework (DNF). Simulated Ordnance Survey DNF polygon data were provided of the same area as covered by the IKONOS MS image. The underlying concept and data that comprise DNF are described in OS consultation paper 1/2000 (OS, 2000a) and a family of related consultation papers available from the OS DNF web site (OS, 2000b) (Harrison *et al.*, 2001) (see <http://www.ordsvy.gov.uk/downloads/dnf/prodspec3/d00506.pdf>).

DNF data are created through a re-structuring of the National Topographic Database, to provide a seamless database of topographic features. Harrison *et al.*, (2001) describe the key elements of DNF from a land use perspective as:

- the provision of a spatially contiguous and maintained set of polygons derived from topographic features, and
- the allocation of a unique identifier, known as a Topographic Object Identifier (TOID), to each polygon

These elements provide the basis for building and maintaining land use data sets by:

- using 'atomic polygons', defined by topographic features, as building blocks for delineating land use parcels, and
- using TOIDs as an explicit link to associate land use information from other sources.

As DNF data were still under development at the time of undertaking the research in this report, the OS supplied a pre-cursor to DNF which had not been subjected to the final quality improvement flowline.

2.3 The CORINE land use classification system

The CORINE classification system contains 44 land-use classes, which are broadly grouped into 5 major (first level) categories: artificial surfaces, agricultural areas, forests and semi-natural areas, wetlands and water bodies. These can be subdivided into a second level, which contains 15 categories. The subdivision of this level to a third level produces the 44 land-use classes (see http://etc.satellus.se/the_data/Technical_Guide/index.htm).

The 44 classes were specified such that they could be predicted across the whole of Europe from remotely sensed imagery. The imagery is intended to be provided by the Landsat Thematic Mapper (TM) or the SPOT HRV sensor, but with considerable reference also to aerial photography, multi-date imagery and maps. The CORINE system is made up of land units no smaller than 25 hectares, each labelled with one third level class.

3 Relation of CORINE Classes to DNF Information

We propose that the CORINE land-use classification can be performed for the UK using Ordnance Survey DNF vector data with supplementary information from high spatial resolution multispectral imagery. This objective is similar to that of populating the National Land Use Database with land use information based partly on DNF (Harrison, 2000; Harrison *et al.*, 2001; NLUD, 2001).

Three third level CORINE classes have been excluded from our classification into the CORINE inventory because they are assumed not to exist in the UK. These are: 'rice fields', 'olive groves' and 'sclerophyllous vegetation'.

The Ordnance Survey DNF data contain polygons, each with several attributes. We chose to use the DescriptiveGroup, DescriptiveTerm and Make attributes. All polygons have a value for the DescriptiveGroup attribute. This attribute describes real-world topographic objects. It is, therefore, a primary source of data for the CORINE classification.

3.1 The DescriptiveGroup attribute

The DescriptiveGroup attribute value 'natural environment' is a very broad category with a large within-class variance. This category, therefore, requires additional information from the DescriptiveTerm attribute to provide useful information for the classification. Thus, for the DescriptiveGroup attribute value 'natural environment', polygons may have more than one DescriptiveTerm attribute.

The DescriptiveGroup attribute value 'general surface' is the value that is used to define any polygon that does not fit with any of the other DescriptiveGroup values. Therefore, like 'natural environment', it is a very broad category. We do not expect that any of the DescriptiveTerm values will apply to polygons with this value. Instead, the 'Make' attribute, which describes whether the feature is human-made or natural, may provide useful additional information for the CORINE classification.

Polygons with the DescriptiveGroup attribute value 'general surface' and the Make attribute value 'natural', 'unknown' or 'unclassified', or even polygons with the DescriptiveGroup attribute value 'natural surface' that have no DescriptiveTerm value, provide very little useful information for the classification. It is these polygons that will need supplementary information from the remotely sensed data.

3.2 Remotely Sensed Imagery

Given the sensor characteristics described in section 2.1 it was suggested that a sensible strategy would be to conduct a per-parcel analysis based on the IKONOS MS imagery and the DNF polygons (Aplin *et al.*, 1999). The spatial resolution of the IKONOS imagery

should be sufficiently fine to provide much within-parcel information for analysis. Indeed, the results of Aplin *et al.*, (1999) and Aplin and Atkinson (2001) illustrate that such a strategy can provide useful land cover information within both urban and agricultural areas.

It was suggested that the IKONOS MS imagery should be used to predict values for two basic attributes that will hold most value for the CORINE classification (and, in particular, the classes that cannot be predicted using the DNF data alone):

Spectral Class

The information provided by the Spectral Class value may be provided in a variety of ways, but should at its most basic contain three classes: 'bright' (such as concrete, soil or bare rock), 'vegetated' and 'dark' (such as water or burnt areas). While some overlap between these classes in spectral feature space may be expected, these classes represent the main land covers that need to be distinguished to populate successfully the CORINE classification.

Local Variance

The information contained in the Local Variance value may again be provided in a variety of ways (e.g., various textural classifiers), but should at the minimum contain the following: 'rough surfaces' (e.g. many naturally vegetated surfaces) and 'smooth surfaces' (e.g. annual crops).

Per-parcel land cover classification was conducted as part of this research, and this is described later in section 5.

3.3 Grouping polygons

Several of the CORINE classes, particularly those that exist as a result of human use of the landscape (e.g., the urban and agricultural classes) are the result of a grouping of particular elements such as buildings, small units of land and fields. Therefore, implicit in the proposed method is a technique to group adjacent polygons together to form a CORINE land unit. For example, where several tens or hundreds of 'building' polygons are found close together, the 'building' polygons and any other polygons between them can be grouped together as an 'urban fabric' (second level category) land unit.

3.4 Size of Polygon Unit

The size of polygons is an important aspect to the classification of some CORINE classes. For example, the third level class 'complex cultivation patterns' is described as being the "Juxtaposition of small parcels of diverse annual crops, pasture and/or permanent crops". The size of the land unit defined by the group of polygons is also important to the classification into some CORINE classes. For example, the third level class 'road and rail networks and adjacent land' is only considered as a class in its own right (rather than part of another class such as an urban class) if this linear land unit is less than 100 metres wide.

Since a single unit of the CORINE classification may be no smaller than 25 hectares, polygons smaller than this size should usually be included in the most appropriate CORINE class to which they are adjacent. This is usually the class with which the small polygon shares the largest boundary because small polygons in DNF data are invariably of types (such as 'building' or 'path') that may be included in almost any CORINE class. An exception to this rule is

when there is an abundance of smaller polygons within a land unit which have all the appropriate attribute values to class the land unit either as 'complex cultivation patterns' or 'land principally occupied by agriculture with significant areas of natural vegetation'. These two CORINE classes are made up of land units that are predominantly smaller than 25 hectares.

3.5 *External Context*

One final criteria that may be used to define the CORINE class of a group of polygons is the external context of the group, that is, what the group is surrounded by. For example, the CORINE third level class 'green urban areas' refers to large (> 25 hectares) polygons that contain predominantly vegetation and that are surrounded by one of the two urban third level CORINE classes.

4 **Proposed Method**

4.1 *Relation between DNF/IKONOS and CORINE*

A table has been drawn up to show the relationships between the DNF and remotely sensed attributes and the CORINE classes. Only the part of the table relating to the use of remotely sensed IKONOS MS imagery is shown here (Table 1).

All the various attribute values that may be assigned to polygons have been arranged into the columns of the table. In some cases, the attribute values only provide useful information for the classification if combined with another attribute value. For example, polygons with the DescriptiveGroup attribute value 'general surface' also require a Make attribute value and/or a Spectral Class or Local Variance attribute value.

The rows of the table contain the first, second and third level CORINE classes. A tick in an element of the table indicates that polygons that fit into that column's category, according to their DNF and remotely sensed attribute values, are integral to that row's CORINE class. The column's category can, therefore, be contained in the group of polygons that make up a land unit of that CORINE class. A cross in an element of the table indicates that a polygon may not belong to the corresponding CORINE class, unless the polygon is smaller than 25 hectares or is part of a road or rail land unit which is less than 100 metres wide.

The table that is presented is not a final product. Some greater understanding of both the CORINE classes and the meaning of the DNF attribute values is necessary to complete the table. It can, however, be treated as a model of the style of table that would be useful in the design of a technique for classifying DNF vector data into CORINE classes with additional remotely sensed information.

key	✓	CORINE land unit is indicated by polygons with these attribute values												
	✗	CORINE land unit does not contain polygons with these attribute values (unless polygons or group of polygons are < 25 hectares)												
		CORINE land unit may contain polygons with these attribute values		DNF attribute that requires supplementary information derived from Ikonos imagery										
	information sources	vector information	DescriptiveGroup attribute	general surface										
			DescriptiveTerm attribute	any										
			Make attribute	natural				unknown or unclassified						
			polygon area	any		<25 ha	any	any				<25 ha	any	
	raster information	spectral class	bright	vegetated		vegetated	dark	bright		vegetated		vegetated	dark	
		local variance	any	any	rough	any	any	any	rough	any	rough	any	any	
CORINE classes	Artificial surfaces	Urban fabric	Continuous urban fabric	✗	✗	✗		✗	✓		✗	✗		
			Discontinuous urban fabric	✗	✗	✗	✓		✓				✓	
		Industrial, commercial and transport units	Industrial or commercial units	✗	✗	✗		✗	✓		✗	✗		
			Road and rail networks and associated land	✗	✗	✗		✗	✗	✗	✗	✗		✗
			Port areas	✗	✗	✗		✗	✓	✗	✗	✗		✗
			Airports	✗	✗	✗		✗	✓	✗	✗	✗		✗
		Mine, dump and construction sites	Mineral extraction sites	✗	✗	✗		✗	✓	✓	✗	✗		
			Dump sites	✗	✗	✗		✗		✓	✗	✗		
			Construction sites	✗	✗	✗		✗	✓		✗	✗		✗
		Artificial non-agricultural vegetated area	Green urban areas	✗	✓			✗	✗	✗	✓			✗
			Sport and leisure facilities		✓				✓	✗	✓	✗		
	Agricultural areas	Arable land	Non-irrigated arable land	✓	✓	✗		✗	✓	✗	✓	✗		✗
			Permanently irrigated land	✗	✓			✓	✗	✗	✓	✗		✓
			Rice fields											
		Permanent crops	Vineyards			✓		✗		✗		✓		✗
			Fruit trees and berry plantations	✗		✓		✗	✗	✗		✓		✗
			Olive groves											
		Pastures	Pastures	✗	✓			✗	✗	✗	✓			✗
		Heterogeneous agricultural areas	Annual crops associated with permanent crops	✓	✓	✓		✗	✓		✓	✓		✗
			Complex cultivation patterns	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓	✗
			Land principally occupied by agriculture, with significant areas of natural vegetation	✓	✓	✓		✗	✓	✗	✓	✓		✗
			Agro-forestry areas	✗	✗	✓		✗	✗	✗	✗	✓		✗

Table 1. (a) Relation of CORINE classes to DNF data and IKONOS MS imagery

key	✓	CORINE land unit is indicated by polygons with these attribute values													
	✖	CORINE land unit does not contain polygons with these attribute values (unless polygons or group of polygons are < 25 hectares)													
		CORINE land unit may contain polygons with these attribute values				DNF attribute that requires supplementary information derived from Ikonos imagery									
	information sources	vector information	DescriptiveGroup attribute		general surface										
			DescriptiveTerm attribute		any										
			Make attribute		natural			unknown or unclassified							
			polygon area		any		<25 ha	any	any			<25 ha	any		
	raster information	spectral class		bright	vegetated		vegetated	dark	bright		vegetated		vegetated	dark	
		local variance		any	any	rough	any	any	any	rough	any	rough	any	any	
CORINE classes	Forests and semi-natural areas	Forests	Broad-leaved forest		✖	✖	✓		✖	✖	✖	✖	✓		✖
			Coniferous forest		✖	✖	✓		✖	✖	✖	✖	✓		✖
			Mixed forest		✖	✖	✓		✖	✖	✖	✖	✓		✖
		Shrub and/or herbaceous vegetation associations	Natural grassland		✖	✓			✖	✖	✖	✓			✖
			Moors and heathland		✖		✓		✖	✖	✖		✓		✖
			Sclerophyllous vegetation												
			Transitional woodland/shrub		✖	✓	✓		✖	✖	✖	✓	✓		✖
		Open spaces with little or no vegetation	Beaches, dunes, sands		✓	✖	✖		✖	✓		✖	✖		✖
			Bare rock		✓	✖	✖		✖	✓	✓	✖	✖		✖
			Sparsely vegetated areas						✖						✖
			Burnt areas		✖	✖	✖	✖	✓	✖	✖	✖	✖	✖	✓
			Glaciers and perpetual snow		✓	✖	✖		✖	✓	✖	✖	✖		✖
	Wetlands	Inland wetlands	Inland marshes		✖		✓		✖	✖	✖		✓		✖
			Peatbog		✖		✓			✖	✖		✓		
		Coastal wetlands	Salt marshes		✖		✓		✖	✖	✖		✓		✖
			Salines		✓	✖	✖		✖	✓	✓	✖	✖		✖
			Intertidal flats												
Water bodies	Inland waters	Water courses		✖	✖	✖		✓	✖	✖	✖	✖		✓	
		Water bodies		✖	✖	✖		✓	✖	✖	✖	✖		✓	
	Marine waters	Coastal lagoons		✖	✖	✖		✓	✖	✖	✖	✖		✓	
		Estuaries		✖	✖	✖		✓	✖	✖	✖	✖		✓	
		Sea and ocean		✖	✖	✖		✓	✖	✖	✖	✖		✓	

Table 1 (b). Relation of CORINE classes to DNF data and IKONOS MS imagery

4.2 CORINE Classification

It is intended that a version of Table 1 be used for the development of a procedure by which polygons are grouped and the development of decision trees by which the groups are classified into CORINE classes. The procedure by which polygons are grouped into a CORINE land unit will vary between classes. Some land units can be assembled very simply by grouping polygons. For example the third level class 'road and rail networks and adjacent land' can be derived simply from the DNF polygons with the DescriptiveGroup attribute values 'road or track', 'rail' or 'roadside'.

Other land units will be more difficult to assemble. For example, we suggest that the land units of urban fabric as well as industrial unit should be assembled using a seed polygon, say one with the DescriptiveGroup attribute value 'building'. The algorithm should then search for nearby 'building' polygons within a short distance and include in the group all polygons between the 'building' polygons that fit into any of the appropriate CORINE third level classes. Whether the resulting land unit belongs to the third level CORINE class 'continuous urban fabric', 'discontinuous urban fabric', 'industrial or commercial units', 'port areas' or 'air communication' can then be determined by assessing what types of polygon the land unit contains and what types of polygon surround the land unit. For example, many small units of vegetation within the land unit may indicate continuous urban fabric. Likewise, a polygon with the DescriptiveGroup 'air communication' within the land unit naturally indicates the CORINE class 'air communication'. An example of the use of the context of the land unit is provided by the CORINE class 'port areas' which can only be located near water.

The order in which classes are defined is important. Because of its special requirement to be less than 100 metres wide, the 'road and rail networks and associated land' CORINE classes should be defined first. Therefore, groups of rail and road polygons that are wider than 100 metres can be ungrouped and the polygons made available for inclusion in other CORINE classes.

There are a few CORINE land units that cannot be identified using only the information discussed so far. These include 'mineral extraction sites', 'vineyards' and 'pastures'. Such land units may be identified using other vector information such as local authority maps. The final stage to defining CORINE land units is to include the polygons that are smaller than 25 hectares that have not already been assigned to a CORINE class. As previously stated, these need to be assigned to the most appropriate of the adjacent classes. The final map would be in vector format, as fits with the aims of the CORINE classification.

5 Per-parcel Classification

To illustrate the use of IKONOS MS imagery for the per-parcel classification of land cover (for subsequent use in populating the CORINE land use classification system) a small area of Chandler's Ford was selected and a sub-image of the IKONOS MS image determined. The four wavebands of this sub-image were then classified into four land cover classes (woodland, smooth grass, rough grass and bare soil) using a standard maximum likelihood classifier (MLC) (Figure 1a). Clearly, there is a lot of within-parcel variation as predicted in section 1.2.

The four classes were chosen to represent aspects of the Spectral Class information described in section 3.2 (in particular, woodland and the two types of grass map onto the 'vegetated' class and bare soil maps onto the 'bright' class). Further, smooth grass and rough grass were not meant to imply Local Variance information. These classes were chosen to differentiate visibly different surfaces in the imagery (probably arising as a result of the age of the grass: rough equates to older, longer grass and *vice versa*). This *per-pixel* classification was then converted into a per-parcel classification by assigning to each DNF polygon its modal class. The result is shown in Figure 1b.

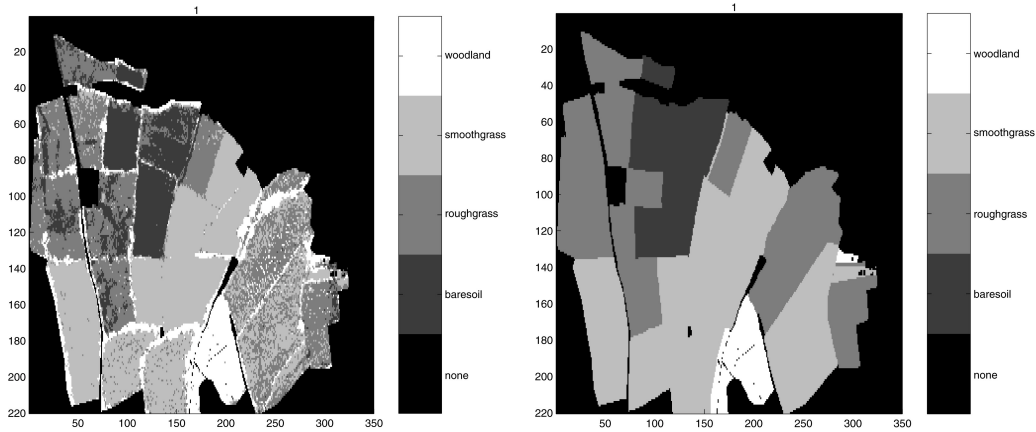


Figure 1. (a) Per-pixel classification of land cover made using the IKONOS MS sub-image of Chandler's Ford; (b) the equivalent per-parcel classification of land cover based on the per-parcel mode in (a).

An alternative to per-parcel analysis of a per-pixel classification may be achieved by classifying the mean spectral value per-parcel. That is, the four waveband values are averaged per-parcel and these averages are then classified using a MLC. This classification is shown in Figure 2. Large differences exist between Figures 1b and 2. In particular, the two large fields to the south-east of the sub-image which were classified as rough grass in Figure 1b are now classified as smooth grass in Figure 2. This difference is minor since grassland is predicted in both cases. Nevertheless, it serves as a useful example of how the stage at which per-parcel amalgamation is made can affect the final classification.

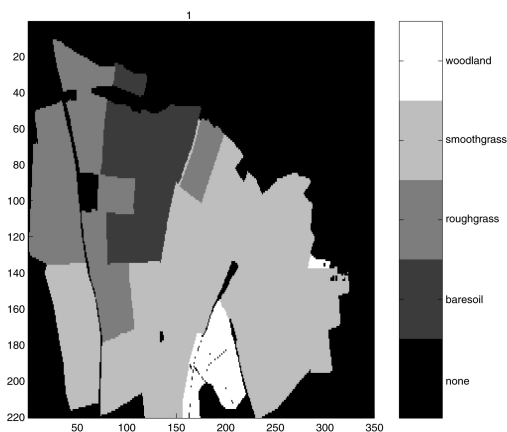


Figure 2. Per-parcel classification of land cover in IKONOS MS sub-image of Chandler's Ford obtained by applying the per-parcel classifier to the per-parcel average spectral values in each waveband of the imagery.

It was suggested in section 3.2 that information on Local Variance in addition to that provided by Spectral Class may be required for classification of CORINE land use. Per-parcel texture analysis has been shown to increase the accuracy with which land cover is classified (e.g., Berberoglu *et al.*, 1999). Therefore, local variance was predicted for the IKONOS MS sub-image using a 3 pixel by 3 pixel local spatial kernel. Then this additional texture information was added to the spectral information available to the classifier. Figure 3a shows the per-pixel classification of land cover based on the original spectral wavebands and the Local Variance texture 'waveband'. The predicted image is very similar to that for Figure 1a suggesting that the Local Variance has added little information of value in this case. Indeed, the per-parcel classification based on this per-pixel classification is identical to that produced without texture information. In the present case, where the region of interest contains mainly agricultural fields, it is not surprising that texture adds little value. Texture may be far more informative where coarse textured areas (e.g., deciduous woodland and urban land) are to be classified together with smoothly textured areas (e.g., agricultural fields).

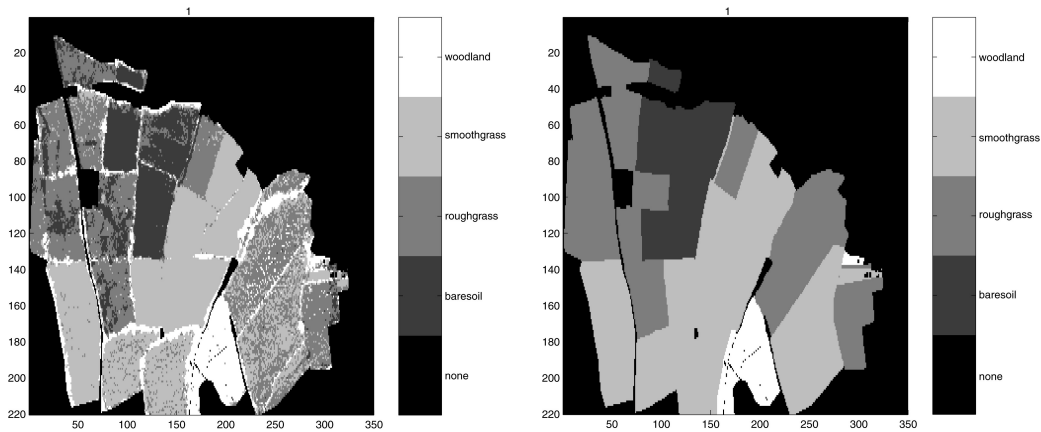


Figure 3. (a) Per-pixel classification of land cover made using the IKONOS MS sub-image of Chandler's Ford, together with a Local Variance 'waveband'; (b) the equivalent per-parcel classification of land cover based on the per-parcel mode in (a).

One of the key Spectral Class values was identified as 'vegetated' in section 3.2. A common means of predicting the amount of vegetation present for a given pixel is the normalised difference vegetation index (NDVI). The NDVI is predicted as:

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (1)$$

where NIR is reflectance in the near-infrared waveband and Red is reflectance in the red waveband. The NDVI is known to be related to variables such as the leaf area index and is often used to predict vegetation quantities such as biomass. The NDVI was predicted for the IKONOS MS sub-image and added to the spectral wavebands and texture waveband infor-

mation available to the classifier. The per-pixel classification obtained based on the three sets of data is shown in Figure 4a. The per-parcel classification obtained by taking the modal class per-parcel is shown in Figure 4b.

The one field in the south east of the sub-image classified in Figure 1 as smooth grass is now classified as rough grass. This change has arisen as a result of a subtle shift towards rough grass at the per-pixel level for the field in question (Figure 4a). However, as for Figure 1b, this difference is of little practical consequence since it relates to one of degree: in both cases the land cover predicted is grassland.

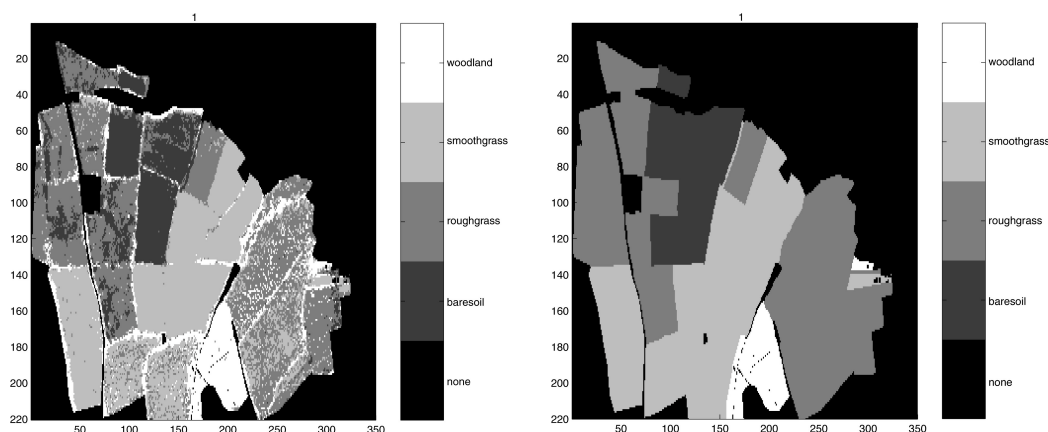


Figure 4. (a) Per-pixel classification of land cover made using the IKONOS MS sub-image of Chandler's Ford, together with a Local Variance 'waveband' and the NDVI 'waveband'; (b) the equivalent per-parcel classification of land cover based on the per-parcel mode in (a).

Once the per-parcel classification of land cover has been undertaken, further processing will be necessary to convert the land cover information into CORINE land use classes. Table 1 suggests the particular CORINE classes that might be predicted from land cover information such as provided in this section. Further, this process might involve textural or contextual analysis as described in the introduction.

6 Conclusions

From the outset, the problems of (i) predicting *land use* from remotely sensed imagery and (ii) misclassification associated with per-pixel classification of land cover based on fine spatial resolution satellite sensor imagery were acknowledged. Guided by these issues, the objective of the present study was to devise a scheme by which the UK could potentially be classified into the CORINE land use classification system based on (i) OS DNF data and (ii) IKONOS MS imagery.

The work was divided into two parts. The first part involved relating the information in DNF polygons to the desired CORINE classes. It was shown that a very large proportion of the CORINE classification could be populated using DNF information alone, without the need to resort to IKONOS MS imagery. IKONOS MS imagery was required mainly to supplement

the DescriptiveGroup attribute General Surface (Table 1), specifically, where the Make attribute was 'natural' or 'unknown or unclassified'. For all other cases, the IKONOS MS imagery was not considered to provide any useful information above that provided by DNF. The second part involved demonstrating the utility of per-parcel classification. The results obtained were similar to those obtained previously (Aplin *et al.*, 1999). Importantly, the per-parcel classification of land cover circumvented the problem of within-parcel variance, although misclassification, when it occurred, involved whole agricultural fields.

In summary, it is recommended that the actual DNF data be used to populate as much as possible of the CORINE land use classification system. The preliminary analysis presented in this paper suggests that a very large number of the CORINE classes can be populated based *only on DNF*. This result is likely to hold true wherever vector or polygon data are available to predict land use. Then, it is recommended that the IKONOS MS imagery be used to predict several of the remaining classes. The results of this investigation suggest that the classes that might not be predicted with DNF data and IKONOS MS imagery combined are small in number (mainly 'mineral extraction sites', 'vineyards' and 'pastures').

7 Acknowledgements

The authors are grateful to the Ordnance Survey for funding this research. In particular, Fred Bishop, Bob Guildford and David Holland are thanked for their input at project meetings and Paul Marshall is thanked for help with image processing.

(Note: references for the main report and for all the annexes are included in a separate reference section at the end of the report)

Oeepe – Project
on
Topographic Mapping from High Resolution Space Sensors

Report by Peter Lohmann, Bernd Haarman, Christian Ausmeyer, Matthias Mosch
University of Hannover

Work package 4 – ‘Automatic Land Use Classification’

This annexe contains the slides of a presentation produced for the OEEPE meeting at the interim stage of the project. The researchers classified the multispectral image using both ERDAS Imagine and Definiens eCognition software and tested the results using land-use validation data from Hampshire County Council (note that this reference data was not based on a CORINE classification).

Although there is no accompanying text, the editors felt that the slide presentation was of some benefit to the report and consequently it is reproduced in full.

Land Cover Classification using **High Resolution** IKONOS Data

Preliminary Results

Damn it
Or
Bless it ????

Peter Lohmann
Bernd Haarman
Christian Ausmeyer
Matthias Mosch



Outline

- Background / Motivation
- Data / Interpretation Key
- First Results using ERDAS
- First Results using eCognition
- Problems
- Conclusion



Background and Motivation

OEEPE Project

„Topographic Mapping from High resolution Space Sensors“

Objectives:

1. To classify land use in a defined area as per CORINE specification.
2. Evaluate the practicality of using High Resolution Sensor data for obtaining information for automatic land use classification
3. Evaluate the achievable accuracy of using High Resolution Sensor data for automatic land use classification
4. Cost benefit analysis of using High Resolution Sensor imagery versus conventional methods
5. Investigate the maturity of software system products to exploit automatic land use classification from High Resolution Sensor imagery



Available Satellite Data

- IKONOS MS Satellite Imagery of the area of **Chandlers Ford UK**
- Processing Level: Standard Geometrically Corrected
- Image Type: MSI (Blue, Green, Red, NIR)
- Interpolator Method: Bicubic
- Multispectral Algorithm: None
- Stereo: Mono
- Mosaic: No
- Map Projection: Universal Transverse Mercator (N, Zone 30, WGS84)
- Product Order Pixel Size: 4.00 meters
- MTFC Applied: Yes
- DRA Applied: No
- Bits per Pixel per Band: 11 bits per pixel



Image Meta Data

Sensor: IKONOS-2

Acquired Nominal GSD (Pan)

Cross Scan: 1.13 meters

Along Scan: 0.97 meters

Scan Direction: 0 degrees

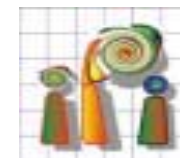
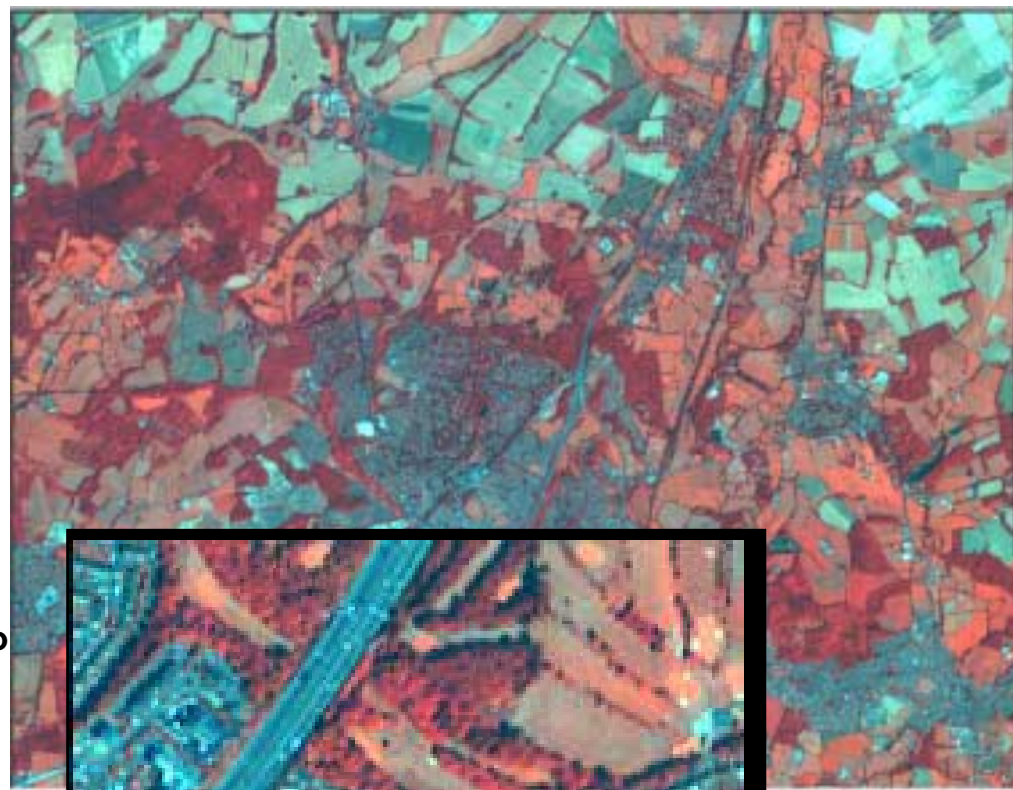
Nominal Collection Azimuth: 255.3399 °

Nominal Collection Elevation: 57.17392 °

Sun Angle Azimuth: 162.2178 degrees

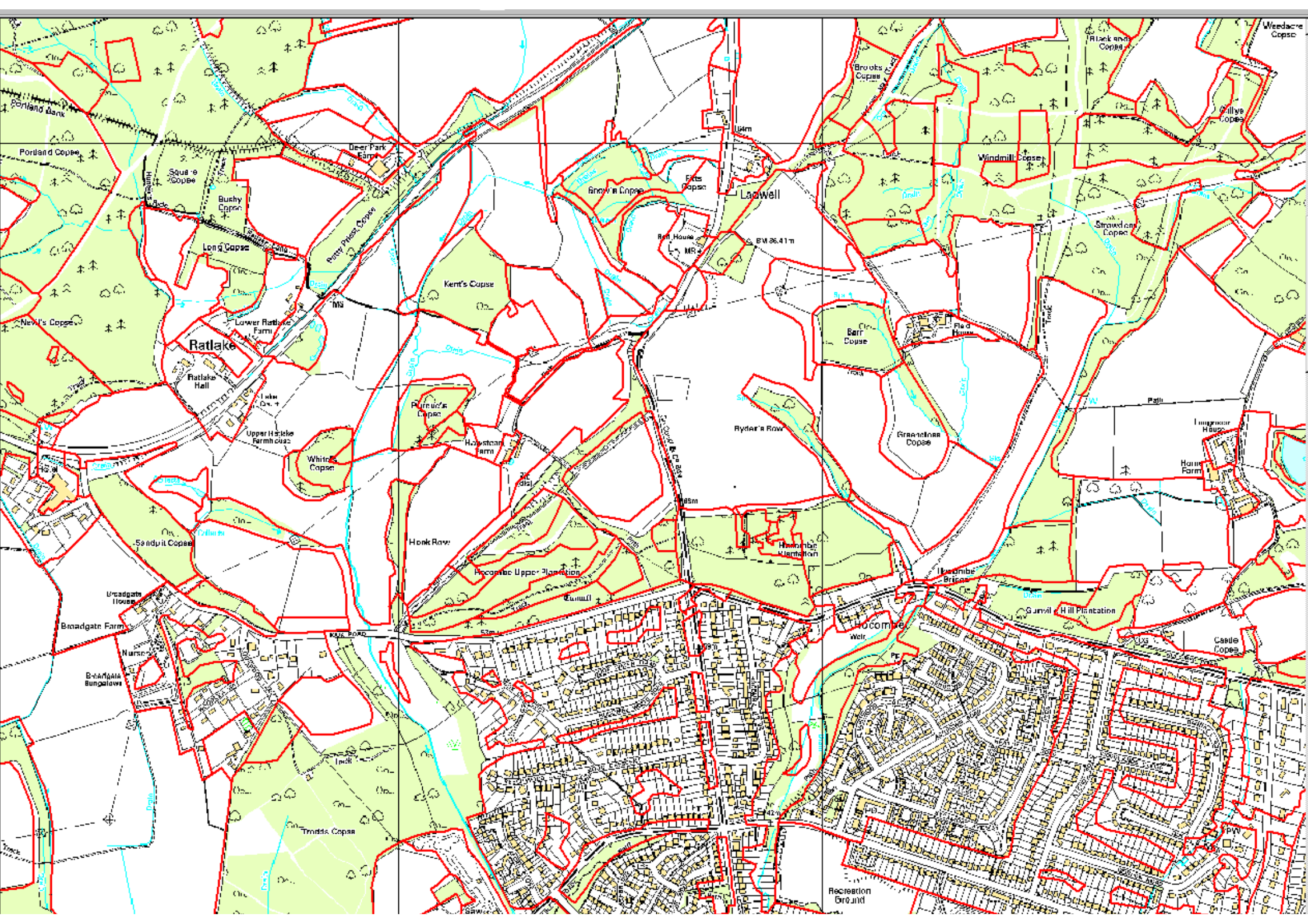
Sun Angle Elevation: 48.60251 degrees

Acquisition Date/Time: 2000-08-25 11:20

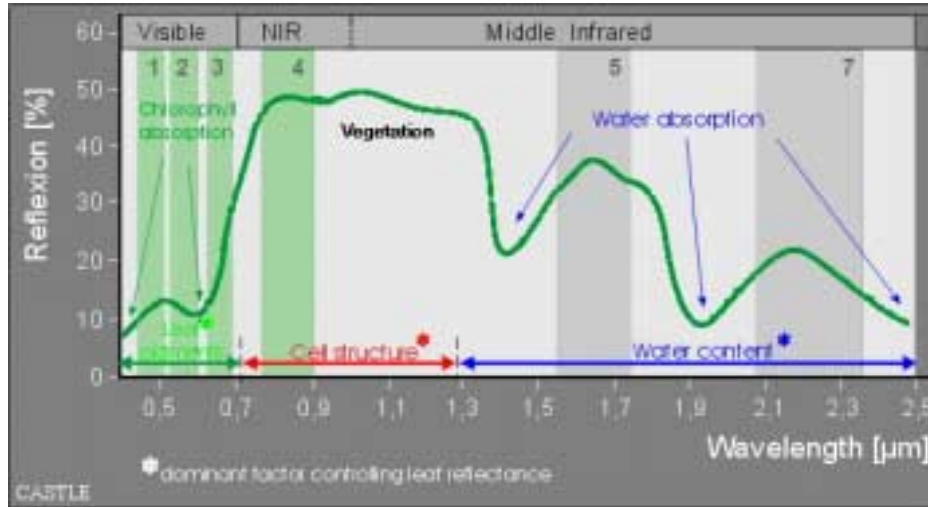


Scanned OS Landplan digital Data (0.635082m) - Tiff-Format





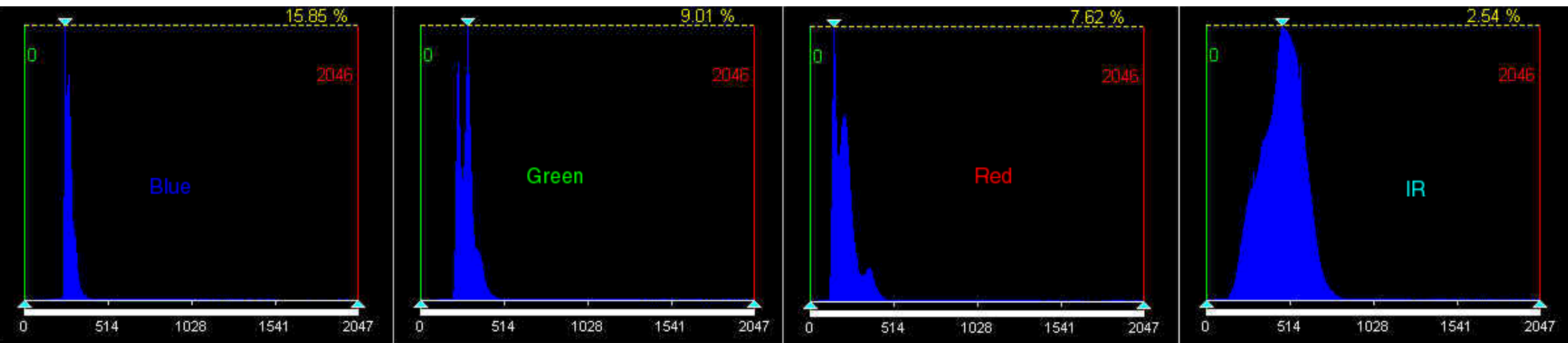
Spectral Properties



Spectral Bands same as
LANDSAT TM 1-4

11Bit

$B1-B3 < 25\% \text{ DR}$; $B4 < 50\% \text{ DR}$



Spatial Resolution

- 4m Pixel → Shadows become more dominant (No Buildings, Trees and other „artificial“ topographic objects without SHADOW !!)
- Resolution not sufficient to differentiate buildings in housing areas



CORINE

44 Landuse units

5 Main categories:

1. Artificial surfaces
2. Agricultural areas
3. Forests and semi-natural areas
4. Wetlands
5. Water bodies

3 Levels of detail

1. Artificial surfaces

1.1. Urban fabric

1.1.1. Continuous urban fabric

1.1.2. Discontinuous urban fabric

1.2. Industrial, commercial and transport units

1.2.1. Industrial or commercial units

1.2.2. Road and rail networks and associated land

1.2.3. Port areas

1.2.4. Airports

1.3. Mine, dump and construction sites

1.3.1 Mineral extraction sites

1.3.2. Dump sites

1.3.3. Construction sites

1.4. Artificial non-agricultural vegetated areas

1.4.1. Green urban areas

1.4.2. Sport and leisure facilities



CORINE Interpretation Key

- Advantage: Common to all EC member states
 - Disadvantage: Key has been designed for statistical tasks (EUROSTAT) and reflects usage types of natural objects rather than land cover types
- ➞ necessitates additional information (GIS-like) in the photo-interpretation process



vs. Urban Vegetation



CORINE Interpretation Key

Variables

Variables Options

Precision of contours: nature of the boundary between two units Sharp, Blurred, Angular, Regular

Colour/hue: depending on vegetation density, slope, orientation All colours (Light/Dark/Pale)

.....

Texture: arrangement of different tones on the image. Texture is defined by

.....

Spatial distribution: indication of the geographical distribution of Longitudinal units in the satellite image as a whole Dispersed, Regular, Irregular, Sporadic.....

Variable Location: description of the normal physiographic positions of the category within an overall landscape.

Example: port area near an urban area

.....



Used Software

ERDAS Imagine 8.4

- Pixel oriented
- GIS functionality (Raster & Vector)
- Knowledge Engineer (Hypothesis, Rules & Variables)
- Interactive refinement of class. results

Definiens eCognition 1.0

- Image analysis (Raster only)
- Segmentation based
- Hierarchical net of image objects
- Knowledge based Classification by membership functions (fuzzy logic)
- Neighbourhood relations



Used Input Data

ERDAS

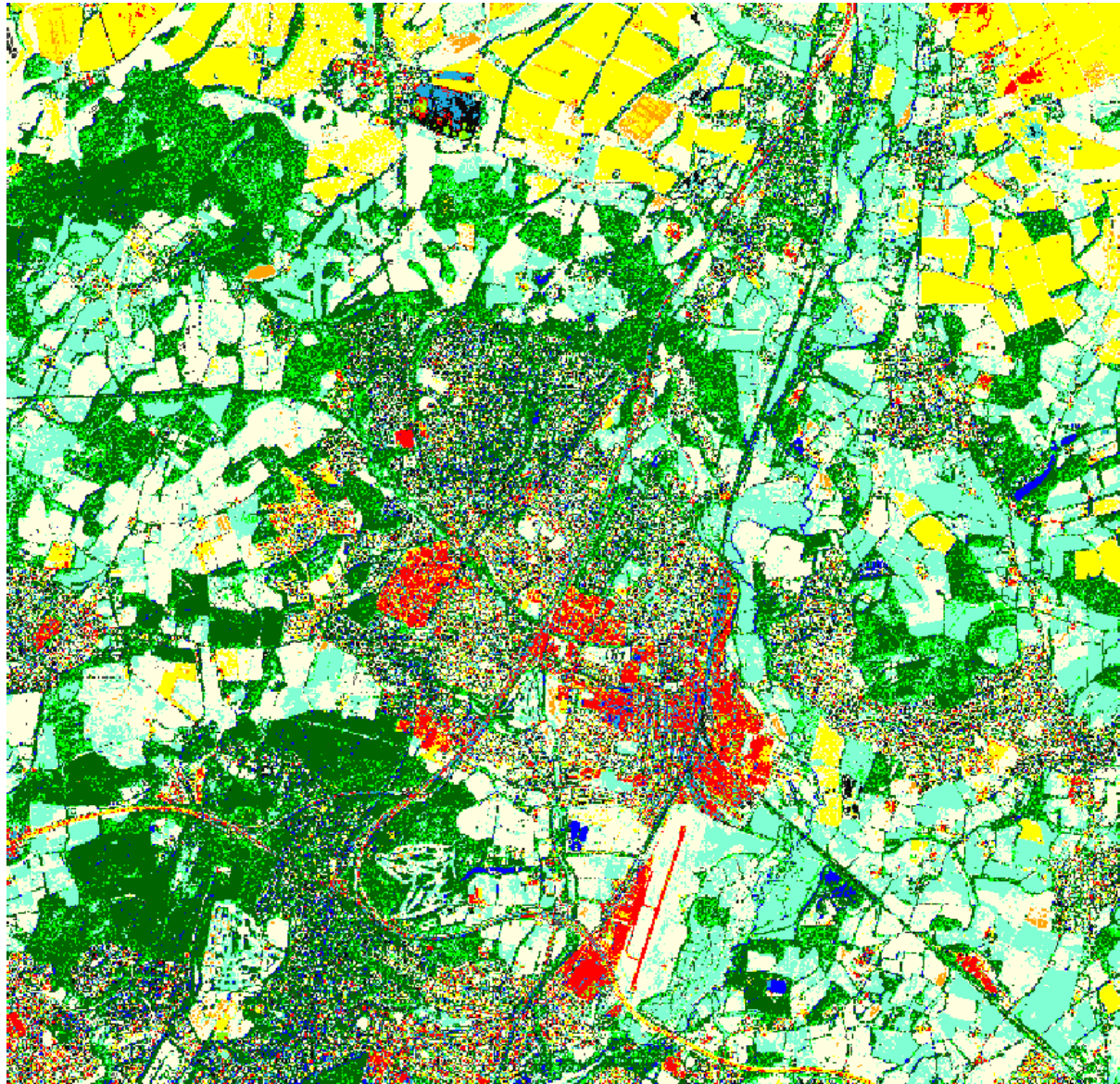
- MS-Channels RGB,NIR
- NDVI
- PC
- Texture (Variance from PC1)
- AOI interpreted from ISODATA and Habitat Map

eCognition

- MS-Channels RGB,NIR
- NDVI
- Texture
- Shape Parameters
- Neighbourhood relations



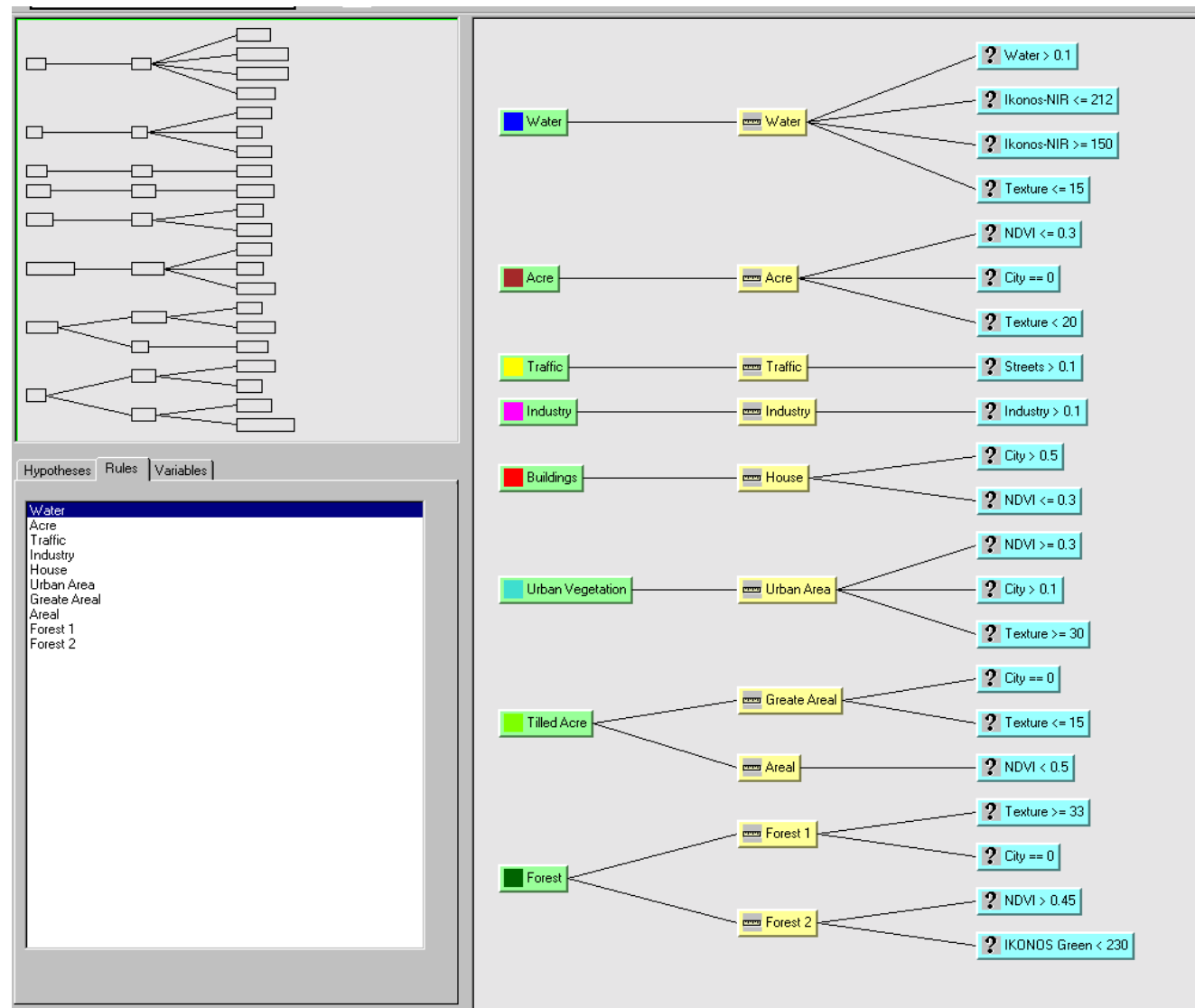
Unsupervised ISODATA classification



Classification using ERDAS

Expert Classifier

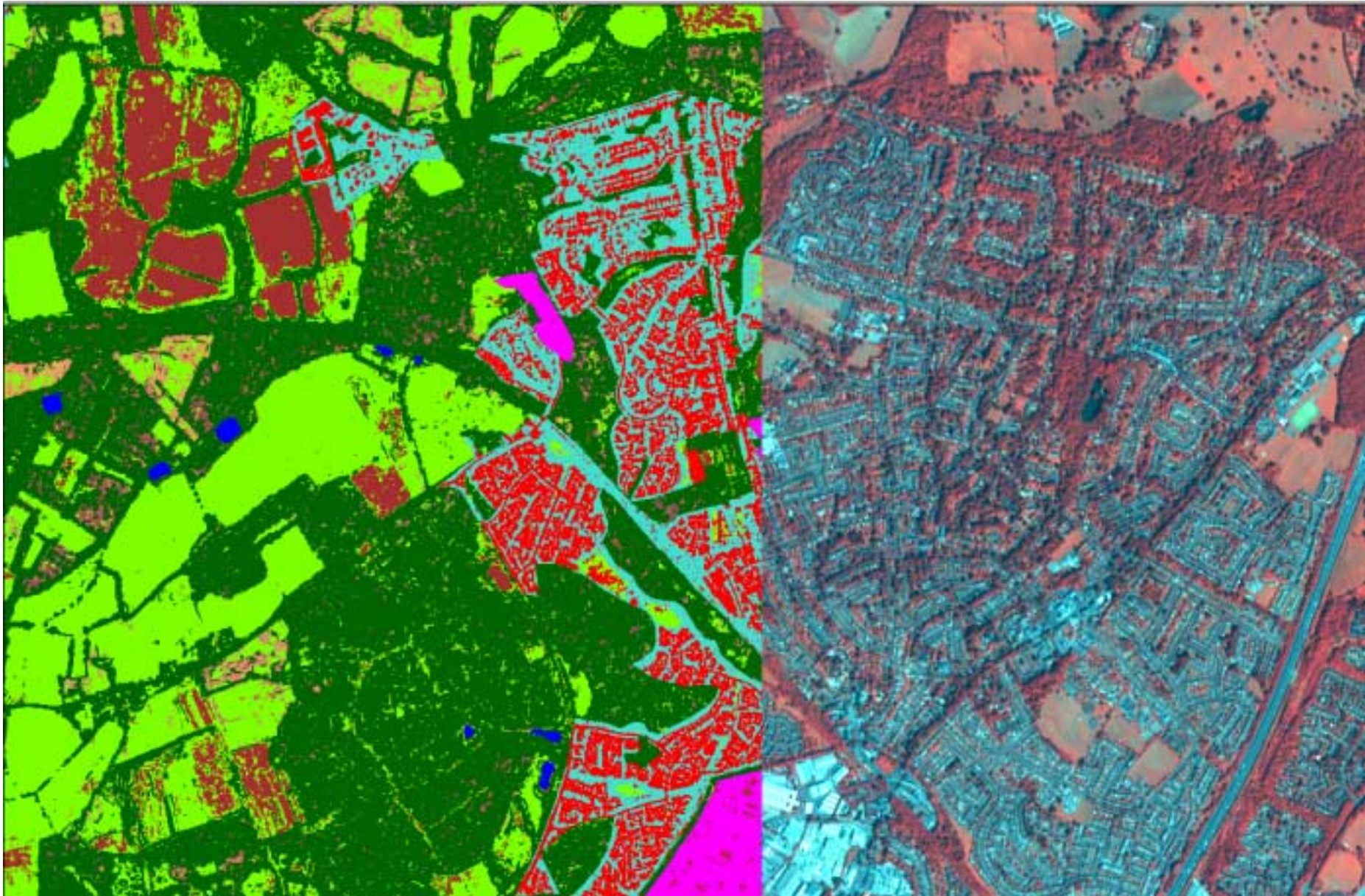
- Texture from 1.PC
- AOI's from ISODATA and Habitat Map
- Thresholds from MS channels



Could be refined (PAN data and GIS missing)



Classification using ERDAS Expert Classifier



Preliminary Accuracy Assessment

Overall Classification Accuracy = 89.00%

KAPPA ($K^{\wedge}$) STATISTICS

Overall Kappa Statistics = 0.8564

Conditional Kappa for each Category.

Class Name	Kappa
Unclassified	1.0000
Water	0.0000
Acre	0.6296
Traffic	1.0000
Industry	1.0000
Buildings	0.8876
Urban Vegetation	0.8792
Tilled Acre	0.8328
Forest	0.9569



Classification using eCognition

Concept:

- Imitates human perception
- Object oriented
- Hierarchical net
- Fuzzy Logic

Most important elements:

- Segmentation based on
 - Spectral homogeneity
 - Knowledge
- Classification based on
 - Spectral information
 - Neighbouring objects



Influence of image object sizes

Small image objects

Advantages:

- No averaging of pixels → no information loss
- Classifications may be used as texture

Disadvantages:

- No representation of shape/structure
- Image objects have no texture

Large image objects

Advantages:

- Large objects may represent shape/structure
- Only large objects have a texture

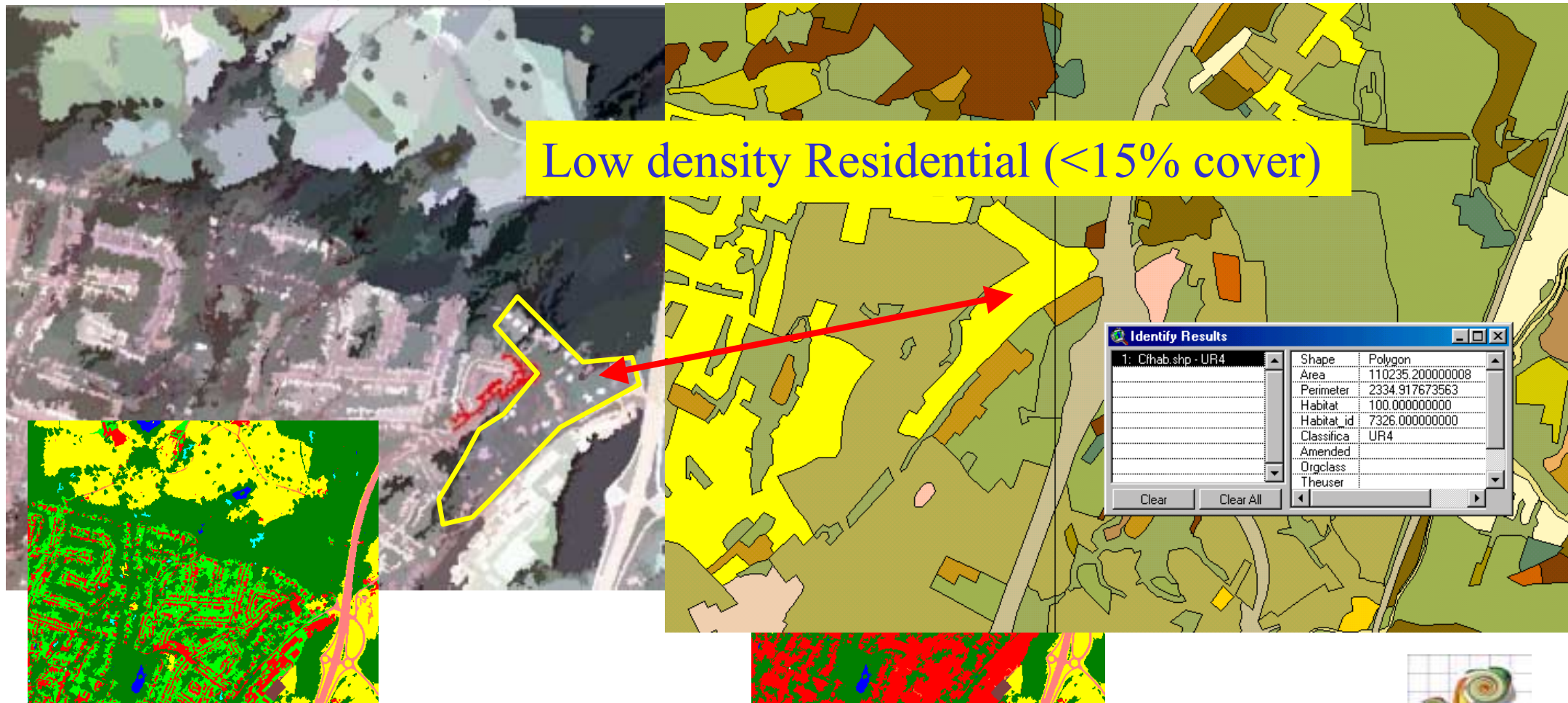
Disadvantages:

- Averaging of pixels → Information loss
- An object may cover more than one landuse class

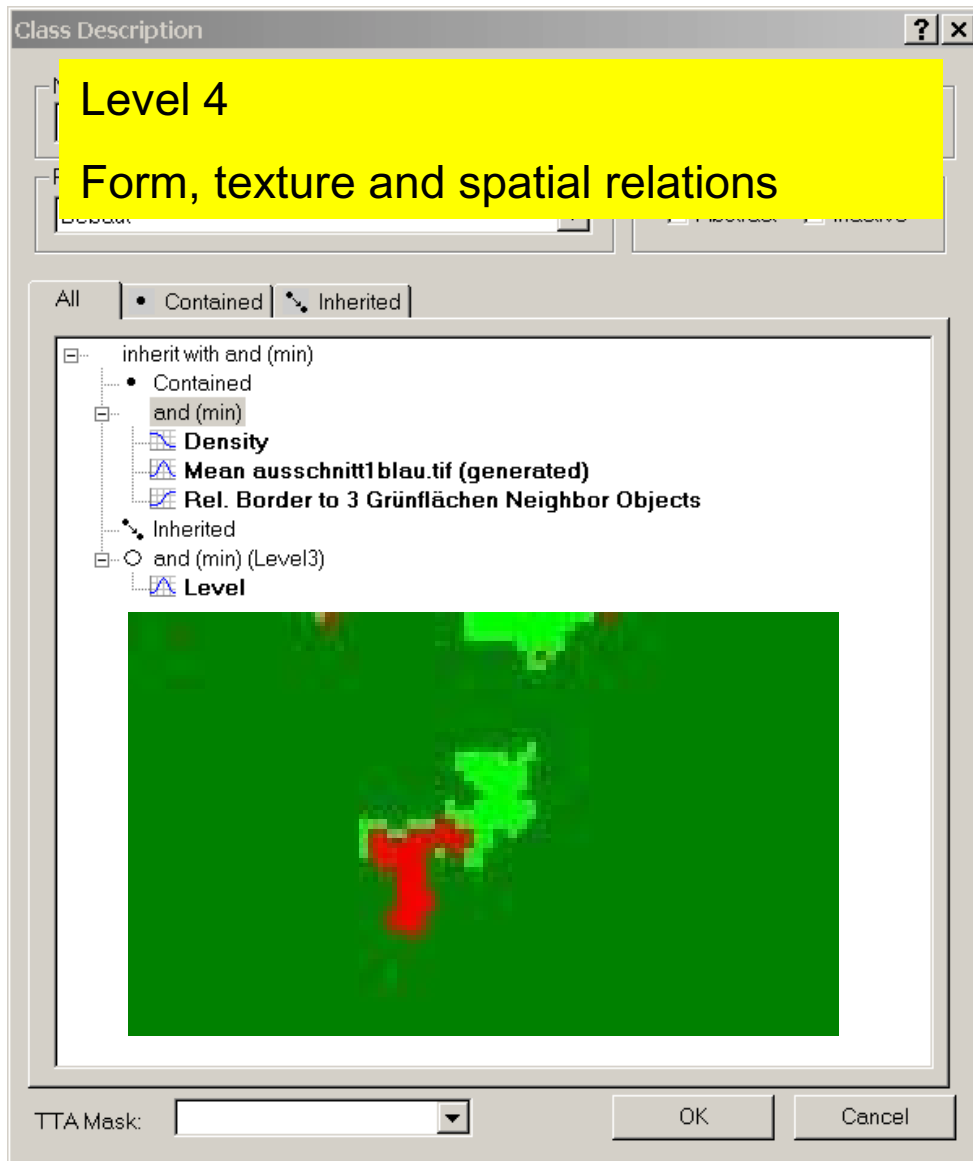


Influence of image object size

Problem: Typical structures may be lost while segmenting relatively large image objects



Use of Superlevels



Level2: Fusion NDVI driven

Level 1 Classification

Pixel level

Level 5 (old level 2)

Level 4 Shape, Texture, Neighbourhood (Large objects)

Level3 Classif. of level 2 and 4 (Medium size objects)

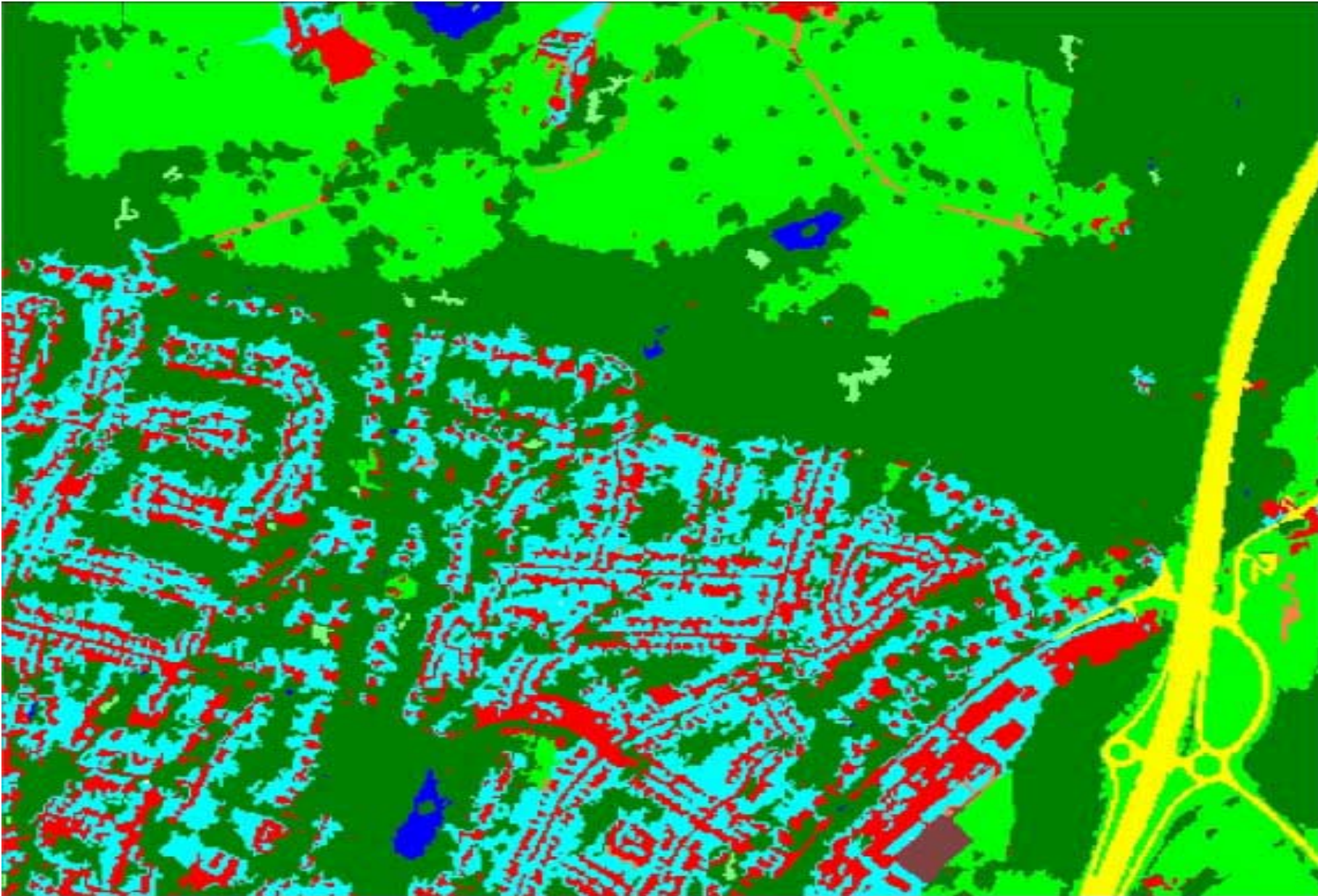
Level 2 spectral values (Small objects)

Level 1 (old level 1)

Pixel level

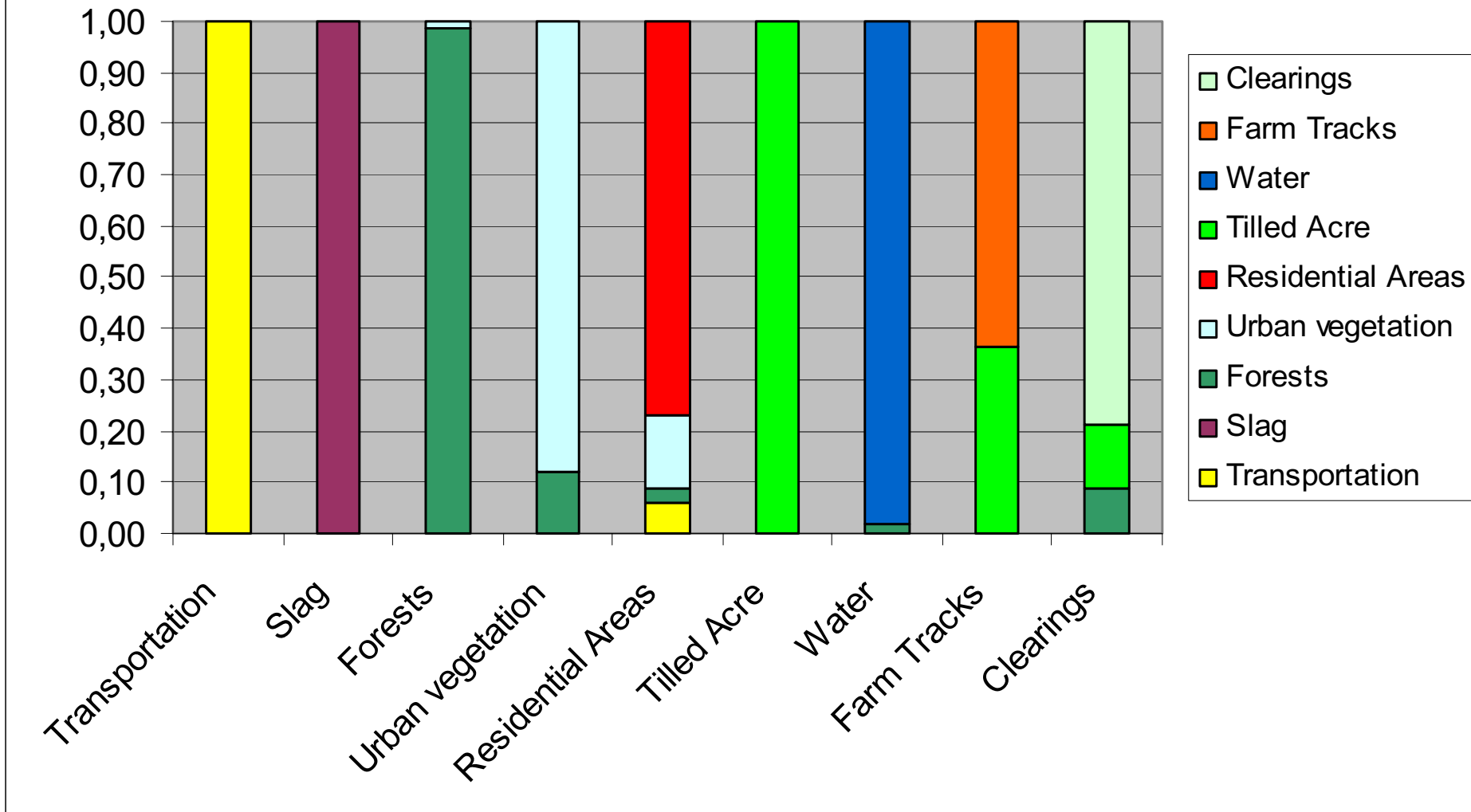


Classification Based Segmentation



Preliminary Accuracy Assessment

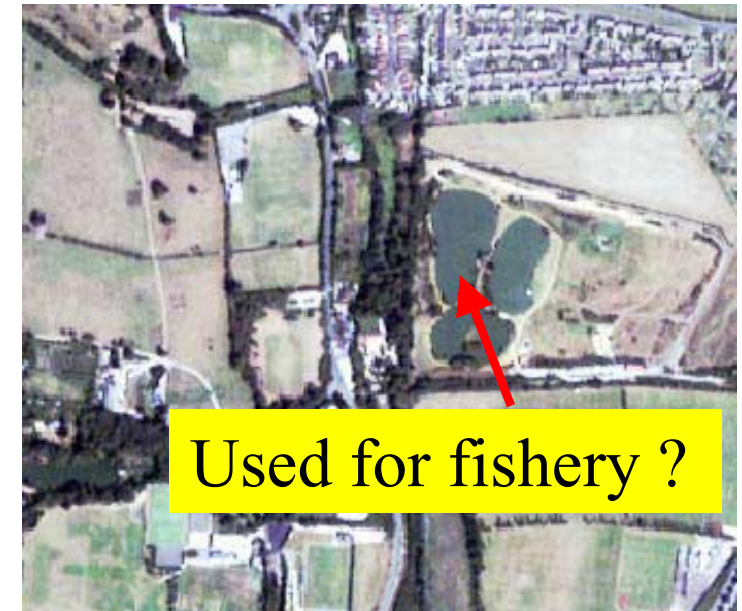
Confusion Diagram



General Problems due to Interpretation Key

Landcover vs. Landuse

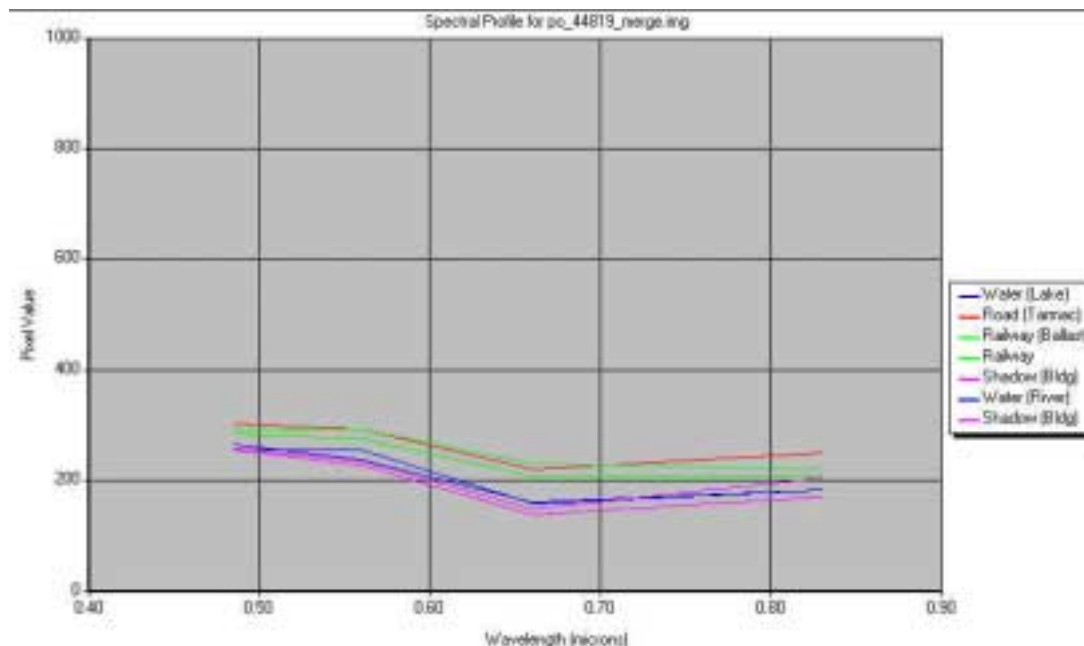
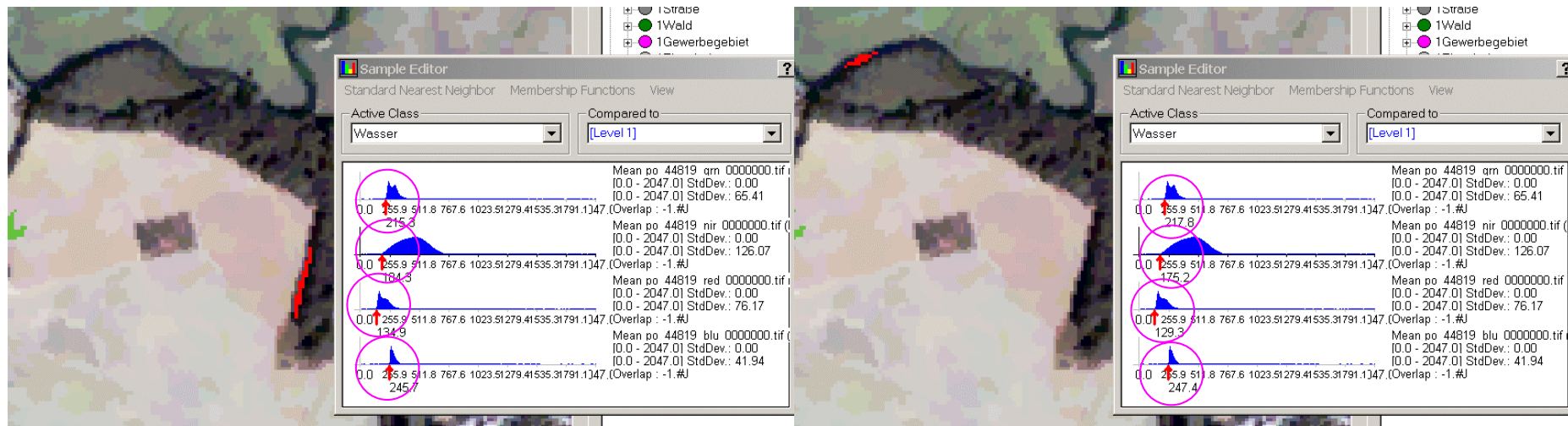
- | | |
|--|--|
|  | UR1 - High density residential (40 % or more cover) |
|  | UR2 - High density, high rise residential (7+ storey) |
|  | UR3 - Medium density residential - normal suburb (15-40 % cover) |
|  | UR4 - Low density residential (<15 % cover) |
|  | UR5 - Caravans and mobile home sites (permanent) |
|  | UR6 - Amenity grassland - parks and formal gardens around buildings |
|  | UR7 - Grass sports fields |
|  | UR8 - Allotments |
|  | UR9 - Cemeteries (not associated with parish churches) |
|  | UU1 - Town centres and high streets |
|  | UU10 - Other buildings |
|  | UU3 - Commercial retail |
|  | UU4 - Industry |
|  | UU5 - Specialised industry (power stations, oil refineries, sewage treatment works) |
|  | UU6 - Outdoor storage (container depots etc) |
|  | UU7 - Transport areas (more than 2mm on photo) - roads, runways, car parks etc) |
|  | UU8 - Institutional buildings - schools, hospitals (significant grass areas will be mapped as amenity) |
|  | UU9 - Unbuilt bare open land - within the urban fabric awaiting development |
|  | W1 - Broadleaved woodland inc carr woodland |
|  | W10 - Felled woodland |
|  | W11 - Ground prepared for new planting- deep ploughed |
|  | W12 - Forestry scrub eg secondary growth after felling |
|  | W2 - Broadleaved plantation |



UR4 Low Density Residential (<15% cover)



Problems due to spectral resolution



Problems due to Spatial Resolution

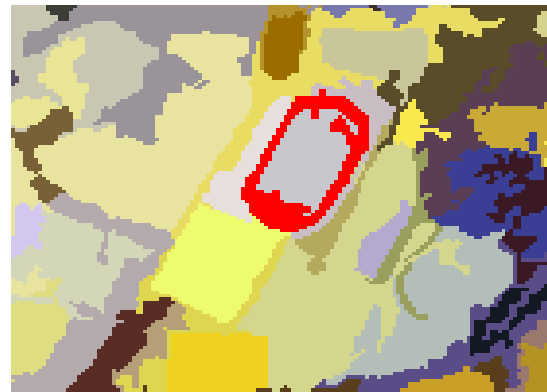
Advantage:

High Resolution permits detailed classification

Disadvantage:

High Resolution yields an increased heterogeneity within fields of same landcover → class assignment becomes more difficult (rules & neighbourhood relationships have to be used)

→ Complexity of Models increases



Conclusions

1. Interpretation key should be adopted to automatic landcover classification (CORINE was made for statistical purposes using photointerpretation)
2. Site specific knowledge (i.e. GIS data & DEM) has to be used. Vector support has to be implemented for eCognition.
3. High resolution PAN data is required for many purposes (separation of streets and buildings,....)
4. High resolution satellite data requires new techniques, which are not restricted to standard statistical multispectral approaches → Image Analysis and Modelling



Conclusions cont.

6. Much more work has to be done to define automatic interpretation rules → semantic modelling
7. Some software additions would be helpful (i.e. vector usage in eCognition).
8. Processing Time especially for eCognition critical (classification based segmentation for a complete IKONOS scene was > 34 hours)
9. eCognition allows to some extend the classification of landuse rather than landcover
10. Interoperability between ERDAS and eCognition would be of help



OEEPE – Project
Topographic Mapping from High Resolution Space Sensors
Report by Bulent Cetinkaya, Mustafa Erdogan, Oktay Aksu, Mustafa Onder
General Command of Mapping, Ankara TURKEY
Work package 4 – ‘Automatic Land Use Classification’

1 Introduction

In order to evaluate the IKONOS multispectral image for classification purposes, a series of qualified collateral data is needed. In this study, both supervised and unsupervised classifications are performed to produce a landcover map for evaluating purposes, as the only collateral data that we have is the landmap of the area which gives limited but up to date information of the area.

2 Unsupervised Classification :

The ISODATA algorithm is used to perform an unsupervised classification. ISODATA stands for "Iterative Self-Organizing Data Analysis Technique." The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration.

For Unsupervised Classification, six classes are chosen. The results for an urban and a rural area are shown in images 1b and 2b . Labelling the classes was quite simple due to a well classified image and the small number of classes.

As seen on image 1b, the infrastructure of the city, buildings and roads are well classified as class 2 (purple). Some large flat buildings and infrastructures with very bright spectral reflectance are assigned to a different class. Their roofs might be made using metal or a different kind of material than the other small buildings and infrastructures. Because of the limitations of the collateral data we cannot be sure about the true nature of these materials. They are represented in the image by the colour tan.

Vegetation is represented by three classes due to the infrared band being sensitive to the vegetation. Dark green, bright green and black colours are assigned to these classes. Grass is represented by bright green, while forests are represented by dark green and black. The forest subject to shadow and the water are usually represented by black. Bare ground with no grass is assigned to class 4, represented in brown.

As we concentrated on the Signature Mean Plot of the classes shown on figure 1, class 1 (black) and class 3 (dark green) have almost the same reflectance in all bands except Infrared. They both represent forest and trees. Class 3 may represent trees in shadow. Bare ground and land with grass also have similar reflectance in almost all bands but with a little shift.

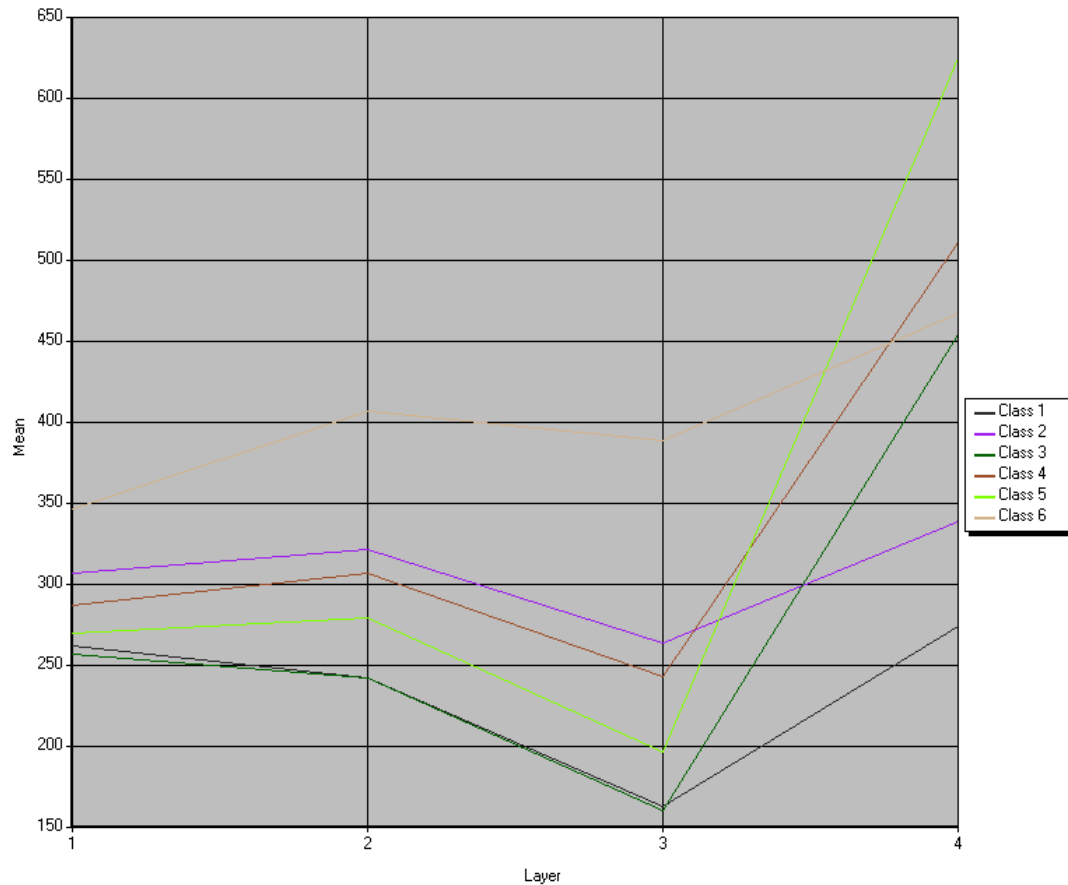


Figure 1: Signature Mean Plot of the Unsupervised Classification

3 Supervised Classification

The decision rules for the supervised classification process are multi-level:

- non-parametric
- parametric.

And there are three different parametric decision rules: maximum likelihood, Mahalanobis distance, and minimum distance. For the supervised classification in this study, only the maximum likelihood decision rule was used.

The maximum likelihood decision rule is based on the probability that a pixel belongs to a particular class. The basic equation assumes that these probabilities are equal for all classes, and that the input bands have normal distributions.

At the start, six classes were identified for supervised classification: forest, water, roads and buildings, green agricultural land, cultivated agricultural land, and bare land.

The result was satisfactory for all classes except the water class. Some lakes and water features on the multispectral image are mistakenly assigned to the roads and buildings class. Another water class, labelled as lake water, was added and the multispectral image was reprocessed for supervised classification. This gave a better result, but there are some water features that are still not identified. The process was rerun after adding another water class, labelled “fisher’s pond”. As a result the total number of classes is increased to eight but there are still only six true classes, as three classes combine to give the water class. Results of the supervised classification are shown in images 1c and 2c.

It is interesting to note that some water features are still misclassified as roads and buildings. These are shown with a red boxes on images 2a. and 2c. The depth, quality, dirtiness of the water itself, the type of the material that lies under the water and the marsh, reeds and other vegetation in the water might give rise to different spectral reflectance. In order to investigate this further, more collateral data would be needed.

In the supervised classification the forest is only represented by one class, coloured dark green. Green agricultural land, cultivated agricultural land and bare land are assigned to different classes, represented by bright green, brown, and tan respectively. Roads and buildings are assigned to a single class, coloured purple. The result was quite satisfactory, but the image still contains some speckle, which can be removed by filtering.

For filtering, a neighbourhood function is used. Neighbourhood functions are specialized filtering functions that are designed for use on thematic layers. Each pixel is analyzed with the pixels in its neighbourhood. The number and location of the pixels in the neighbourhood are determined by the size and shape of the filter, which is user-defined.

Each filtering function results in the centre pixel value being replaced by the result of the filtering function. The filtering function used in this case is “majority”, in which the centre pixel is replaced by the most common data value in the neighbourhood.

At the start, a 3x3 window is selected as the kernel size for filtering. The speckle is removed from the output classified image and the resulting image seems sharper than the original classified image; especially when focussing on lines and buildings (images 1d and 2d). The forest area seems much more homogeneous, but differentiation of the separate buildings is not so clear.

The use of a kernel size of 5x5 for filtering (see images 1e and 2e) resulted in the loss of much of the information in the classified image. However, if a smooth output is required from the classification, this filter may be useful. The process results in a lower degree of precision at the individual pixel scale, but may be of interest at a more general scale. For example it could be used in forested areas to determine the general area of forest (ignoring small patches of bare land and tracks and paths within the forest).

4 Conclusion

The multispectral Ikonos imagery proved to be capable of differentiating between six classes of land cover, using a cartographic map as “ground truth” data. Further work would be required to assess the accuracy of the classification with respect to a more detailed ground truth dataset.

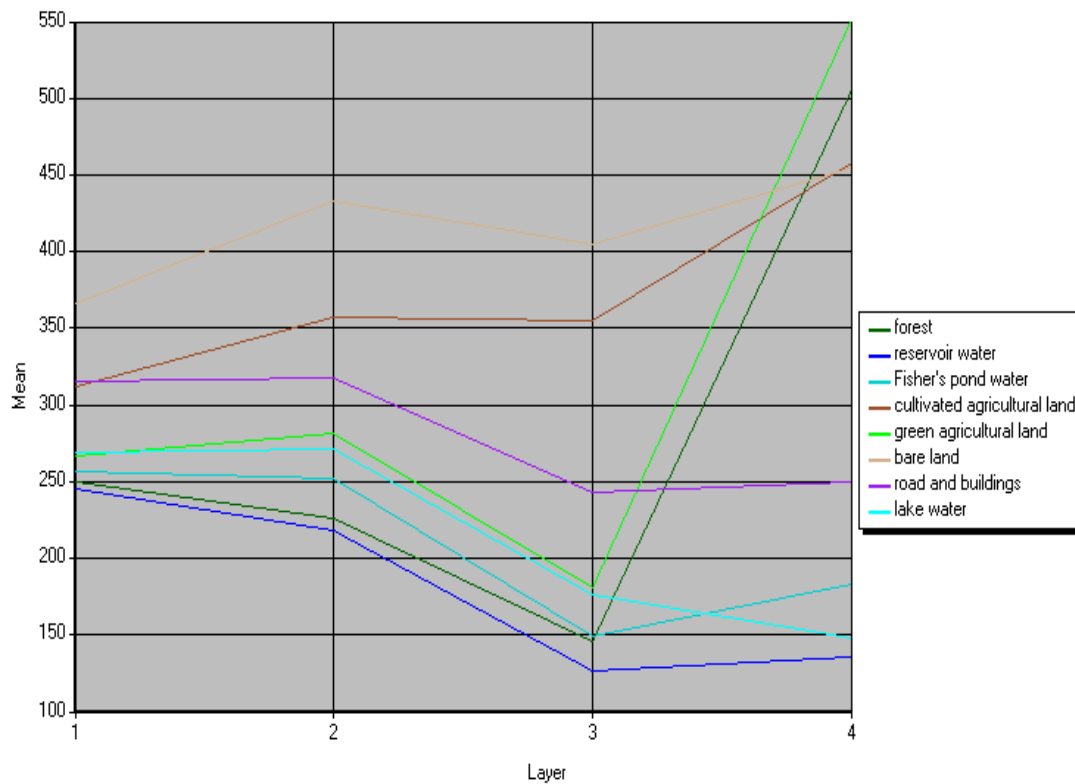


Figure 2: Signature Mean Plot of the Unsupervised Classification



Image 1a : IKONOS Multispectral Satellite Image (4 metre)



Image 1b : Unsupervised Classified Image (six classes)

Row	Histogram	Color	
0	76034		Unclassified
1	1083520		Class 1
2	1006239		Class 2
3	1718206		Class 3
4	1480975		Class 4
5	1902048		Class 5
6	792883		Class 6



Image 1c : Supervised Classified Image (eight classes)

Row	Histogram	Color	
0	76034		Unclassified
1	2064621		forest
2	10614		reservoir water
3	15503		Fisher's pond water
4	898554		cultivated agricultural land
5	471967		bare land
6	932401		road and concrete structure
7	3587004		green agricultural land
8	3207		lake water



Image 1d : Supervised Classified Image after neighbourhood filtering (3x3)



Image 1e : Supervised Classified Image after neighbourhood filtering (5x5)

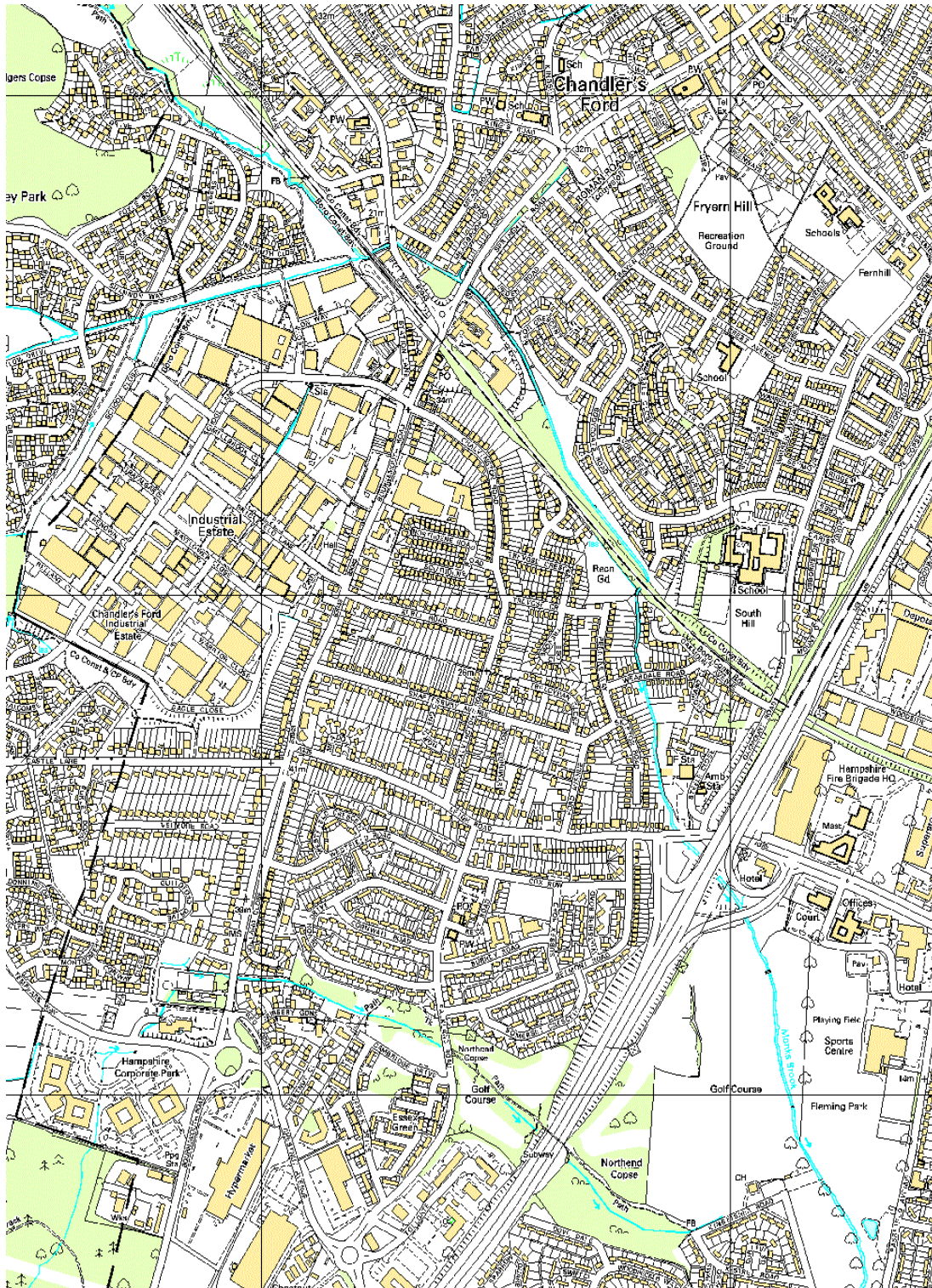


Image 1f : Landmap (Ordnance Survey 10K raster) of the area of interest



Image 2a : IKONOS Multispectral Sattelite Image (4 metre)

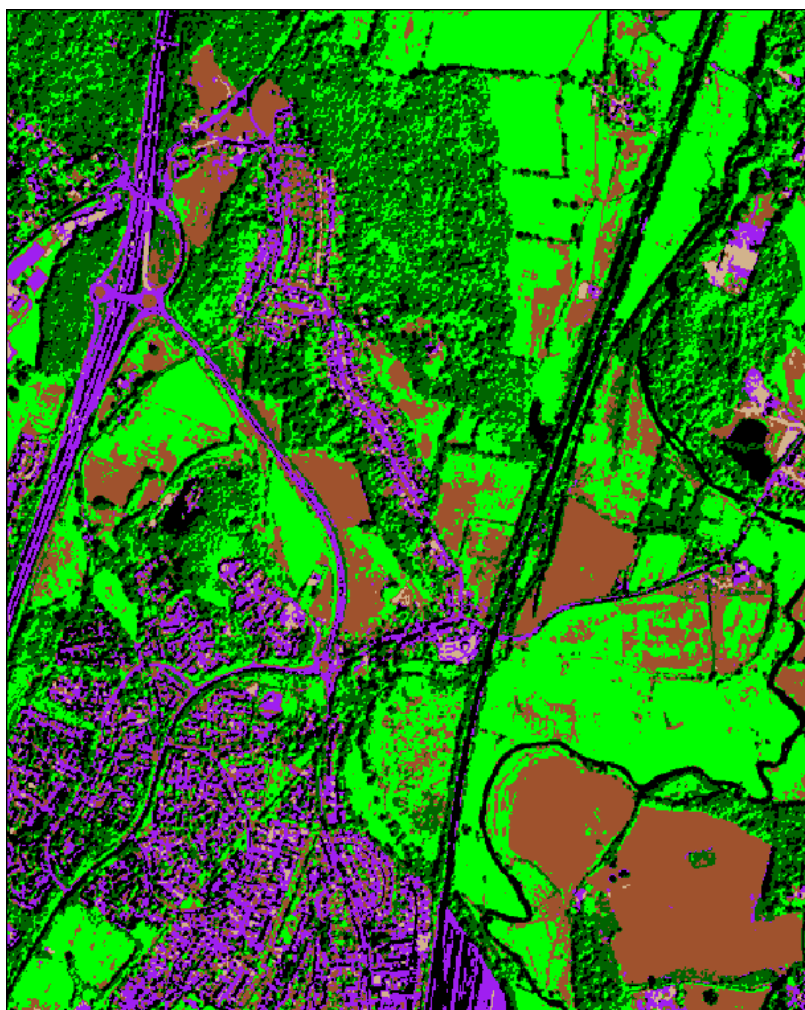


Image 2b : Unsupervised Classified Image (six classes)

Row	Histogram	Color	
0	76034		Unclassified
1	1083520		Class 1
2	1006239		Class 2
3	1718206		Class 3
4	1480975		Class 4
5	1902048		Class 5
6	792883		Class 6

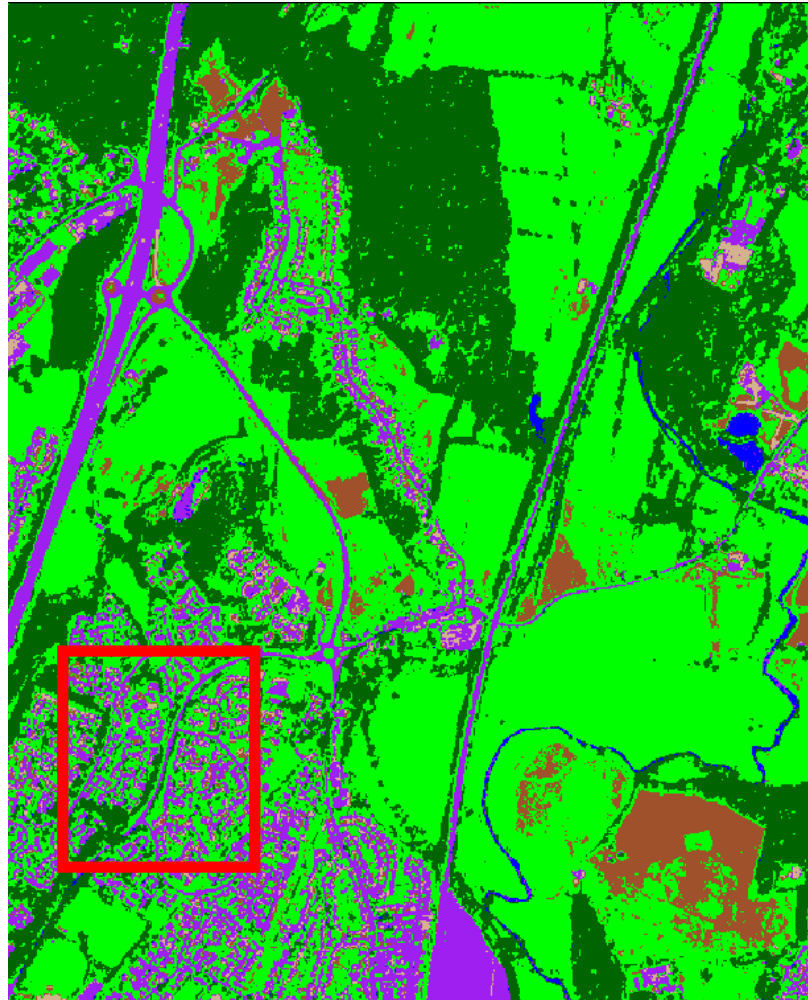


Image 2c : Supervised Classified Image (eight classes)

Row	Histogram	Color	
0	76034		Unclassified
1	2064621		forest
2	10614		reservoir water
3	15503		Fisher's pond water
4	898554		cultivated agricultural land
5	471967		bare land
6	932401		road and concrete structure
7	3587004		green agricultural land
8	3207		lake water

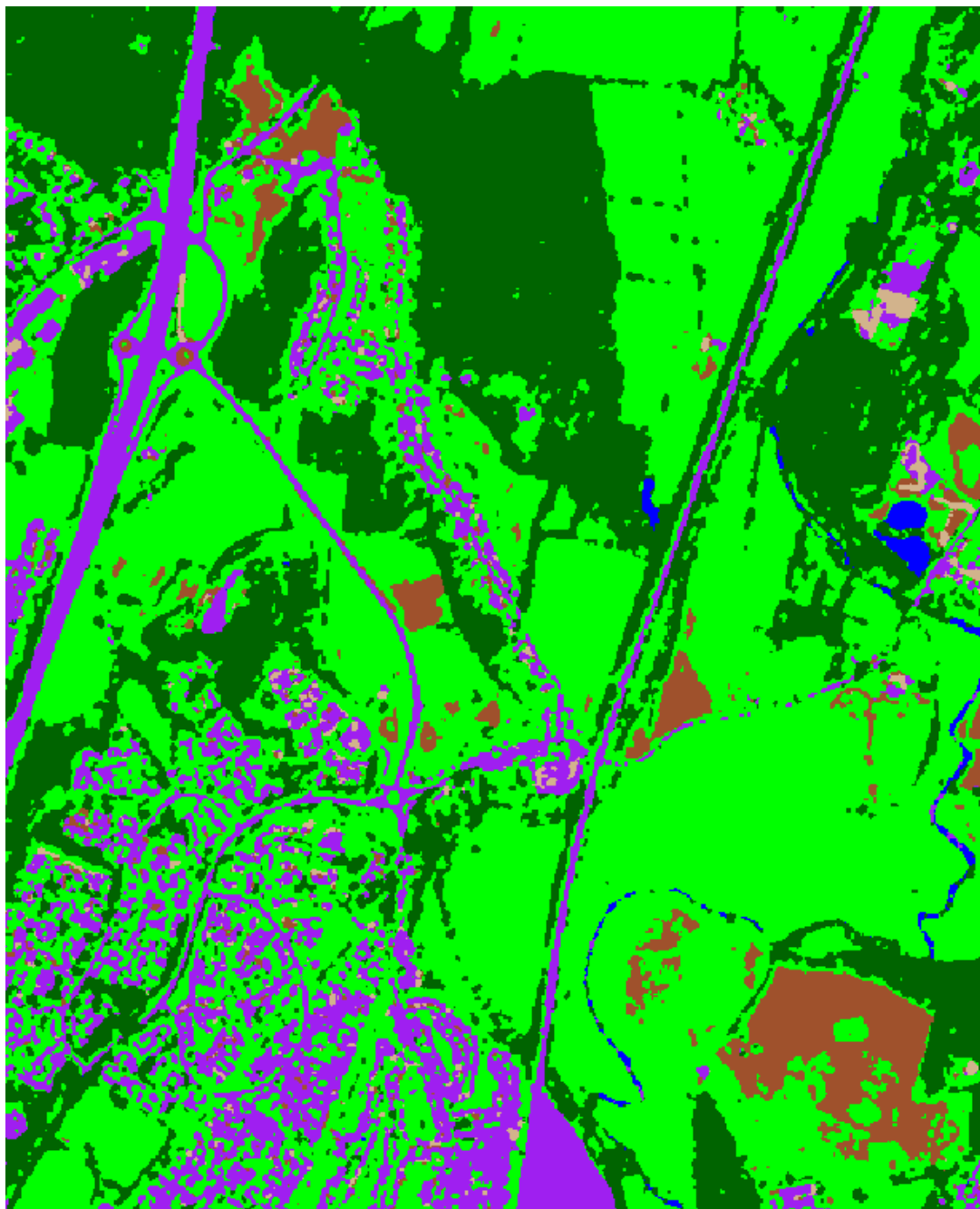


Image 2d : Supervised Classified Image after neighbourhood filtering (3x3)

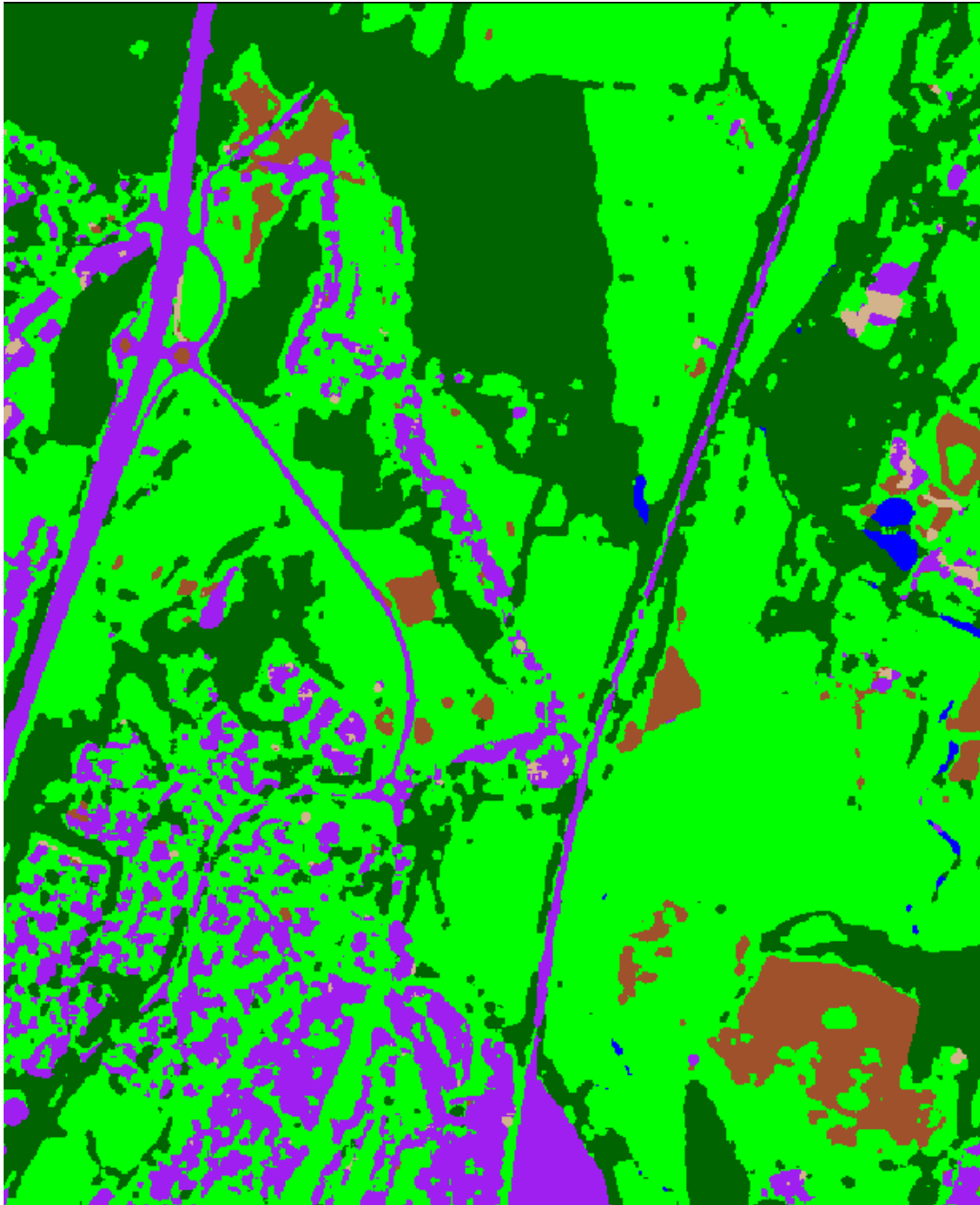


Image 2e : Supervised Classified Image after neighbourhood filtering (5x5)

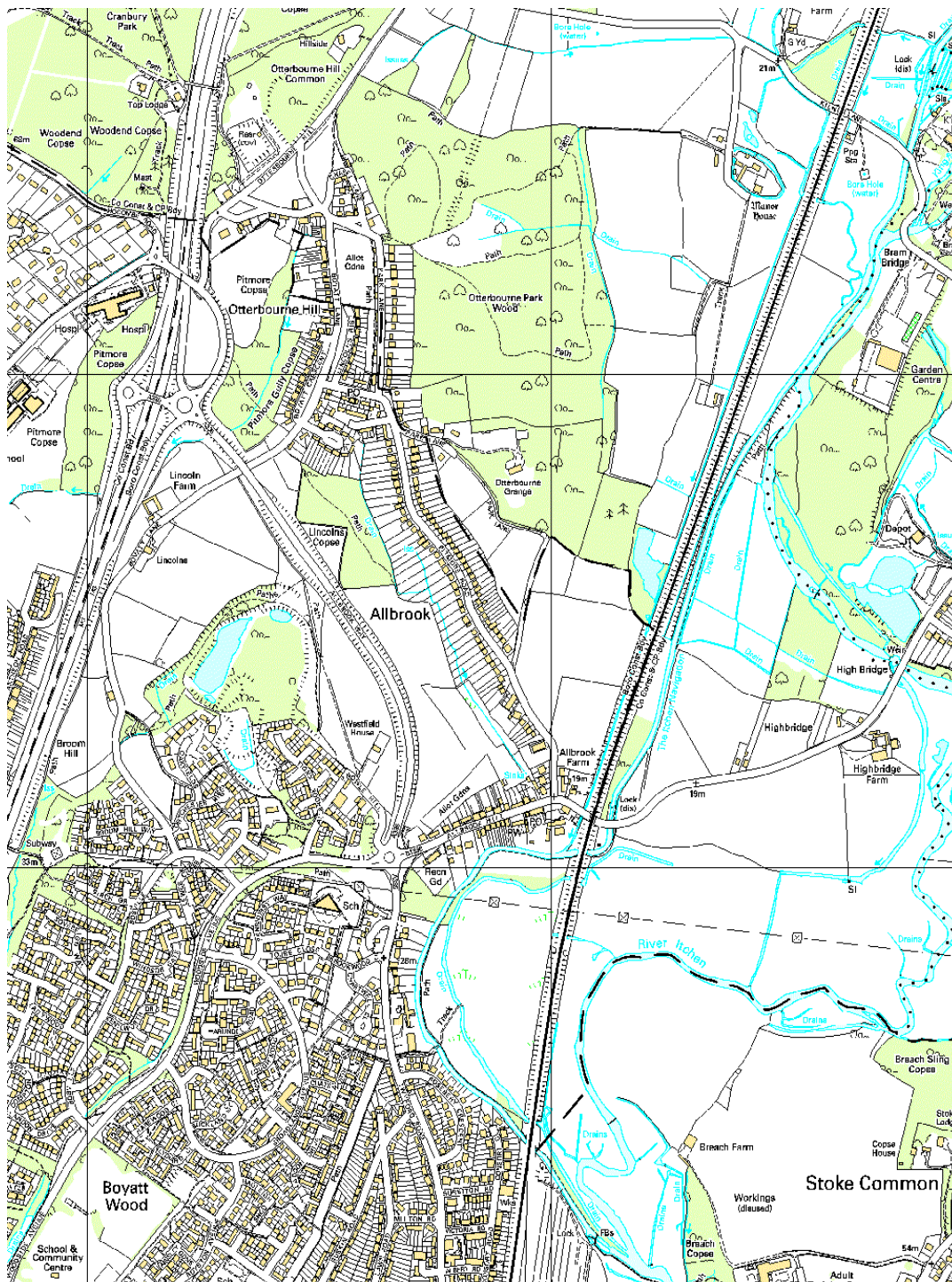


Image 2f : Landmap (Ordnance Survey 10K raster) of the area of interest

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