Automatic generation of image ground control features from a digital map database

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Abstract

In order to register satellite image data to ground coordinates, it is necessary to identify corresponding features in the image and in a reference dataset in a known position on the earth's surface. Previous work in this Alvey project[3] has shown that digital map data of sufficient quality can provide such reference information.

This paper reports work on the automated selection of reliable ground control features from a digital map database. Techniques include the use of a quadtree spatial index to extract data on the basis of feature type and location. Other methods based on feature size and shape are reported. An important aspect is shown to be the establishment of reliability criteria for each feature.

The selected control features may be directly converted for use in automatic image matching software to allow absolute orientation of satellite images based on a large number of control points.

Introduction

To most effectively exploit remotely sensed images, it is vital to relate them accurately to the earth's surface. In general, remotely sensed images will contain distortions due to satellite movement and relief displacement. The process of measuring and characterising this distortion, in order to correct it, is known as image orientation. Image orientation can be achieved in two stages; inner orientation and space resection.

The relationship between the sensor and image plane will generally be known (ie the sensor focal length and position of the image on the focal plane).This is known as the 'inner orientation'.

The orientation of any image vector can easily be found if the *satellite movement in space and time* are known. This time varying trajectory is characterised by six parameters; the 3D position in space of the sensor and its yaw, pitch and roll relative to the fixed sensor axes. The parameters are determined by

[3]'Real time 2.5D vision systems' (U.K. Government information technology project – MMI 137) in collaboration with Thorn EMI Central Research Laboratories, The Royal Signals and Radar Establishment and University College, London - department of Computer Science.

comparing the two dimensional image coordinates and the three dimensional ground coordinates of three or more ground control points. At only one position and orientation in space will the ground points give the correct perspective projection onto the image plane. This is found by an iterative process known as 'space resection' [Gugan 87].

Suitable ground control points, or in general, ground control features (GCFs) are therefore required for the accurate absolute orientation of satellite imagery and may be provided from a number of sources including ground surveys, hardcopy or digital maps, photogrammetric measurements or from satellite global positioning systems.

For computerised estimation of absolute orientation, the ground control points must be in digital form, and the complete dataset containing them will be referred to as the **digital map database**. Thus, the methods for feature extraction presented here only address well-mapped parts of the planet. However, as digital mapping becomes more widespread, and as selected highly accurate GCFs are recorded, future users of satellite imagery will have a ready-made source of ground control. It is the selection of the ground control from such a database that is the subject of this paper.

Feature selection will depend on a number of factors including the feature's visibility (which determines the ease of automatic identification), and the matching strategy used. Other factors such as feature accuracy (which means features which are well defined with an invariant location), and their distribution within an image are also important.

This paper will present a step-by-step approach to automatic feature selection and describe the tools that have been developed. Examples are taken from digital map data in the UK and a database of map and ground control points being collected for the Aix-en-Provence region of France. The application of ground control to SPOT imagery is described.

The digital map database

Construction of a digital map database is an essential prerequisite for automated feature extraction. Such data is stored in a vector oriented form where curvilinear features are commonly represented as 'sufficient' straight line segments. However, vector data can also be more abstract, with 'defining' points being stored, and the actual line generated when necessary; this approach is commonly used for circles, arcs or mathematically defined curves. More complex formats allow linkages between items, giving link and node structures, or polygonal structures (allowing the representation of area features). Hierarchical data is also becoming increasingly common, particularly in geographic information systems (GISs), where one piece of vector data may be used in the representation of more than one feature (for instance, a wall may be part of a house and also the edge of a roadway). This contrasts with raster data, where each pixel may be shared by several features, and the degree to which this ownership can be stored is limited by the number of bits used to represent the pixel.

The principal components of a digital map database [Jackson *et al* 88] are:

- the map data itself
- *meta-data* i.e., data describing the data (quality, source etc)
- various spatial indexes into the data

This section will concentrate on two aspects of the database of particular relevance to feature extraction — a feature based storage mechanism and a quadtree spatial index into the data.

Feature based storage

Vector data is often organised as an unordered list of items in which each item or 'feature' may be identified as a particular object of interest such as a road or a house. It is normal to assign a feature code to each feature, to identify what it is representing. In simple datasets, each feature may have a single code to identify it, and in more complex datasets features may have multiple feature codes, allowing several properties to be attached. In even more sophisticated representations, the features are built into higher level 'objects' [Green and Rhind 86].

As one component of an overall digital map database Laser-Scan have developed a feature based method of data storage called IFF [Hartnall *et al* 86] . This is a vector orientated format using floating point numbers for coordinate storage. As implemented on DEC VAX machines the F_floating format has a range of 0.29E-38 to 1.7E38 with a precision of one part in 2^{23}, or about 7 decimal digits.

Recent further developments have allowed the 3D coordinate storage capacity to be generalised to a multi-dimensional 'coordinate block' entry. Each entry has a header containing the number of dimensions, and a description of each dimension. Per-point attributes such as multiple heights, source and confidence or accuracy are held as extra dimensions in this structure e.g.:

x	y	z_1	z_2	source	confidence
341.4	214.4	310.0	100	1	0.9
145.8	617.3	250.0	100	2	0.7

A hierarchy is observed, such that a set of map attributes apply globally, except where overridden by feature attributes, which in turn may be overridden by individual point attributes. Note that coordinate blocks can be designed to contain just those attributes relevant to an individual point, and null fields are avoided.

An extensive suite of programs exist to convert data from and to a number of standard interface formats (eg [NTF], [OSTF], DLG3, DXF etc.).

Quadtree storage of vector data

Recent work on the design of GISs [Gahegan and Hogg 86], [Mark and Lazon 84], [Samet *et al* 85] has highlighted the use of quadtree structures as a flexible and appropriate approach for the storage, manipulation and access of spatial data. A quadtree is a tree structure of order 4 used to order space by its regular rectangular decomposition [Jackson and Mason 86].

The main reason for applying quadtrees to map feature selection is to provide a two-dimensional spatial index which is missing from vector data. (Even within a true link-node structure, there is no explicit relationship between points in two adjacent features). Quadtrees can provide efficient answers to problems expressed as "find the closest feature to this point".

Much work on quadtrees has been aimed at their use with raster data, and problems, especially of resolution, can occur when extending to vector data [Waugh 86].

The quadtree approach developed within this project [Ibbs and Stevens 87] maintains floating point vector data, rather than trying to convert it to raster data, so there is no requirement to decide upon an accuracy or precision before using the system. The form of quadtree used is a modification of the PM_3' quadtree [Samet and Webber 85]. The leaf nodes of the tree may contain at most one vertex, but as many line segments as necessary.

Software has been written to generate such a spatial index from map data held in IFF form. This has be applied to map regions corresponding to the satellite imagery in our test areas (figure 1). Quadtree Feature coding of vector data is used within the quadtree in an analogous way to the 'colour' of pixels. As there are a very large number of allowable codes, the individual feature types have been allocated to feature code groups (e.g. for water features, roads and paths etc). This grouping reduces the number of classes to be coded, allowing the use of a bit-coded 'colour' to identify each leaf according to the features implicated in it. These colours were then propagated up the tree; each internal node having a colour

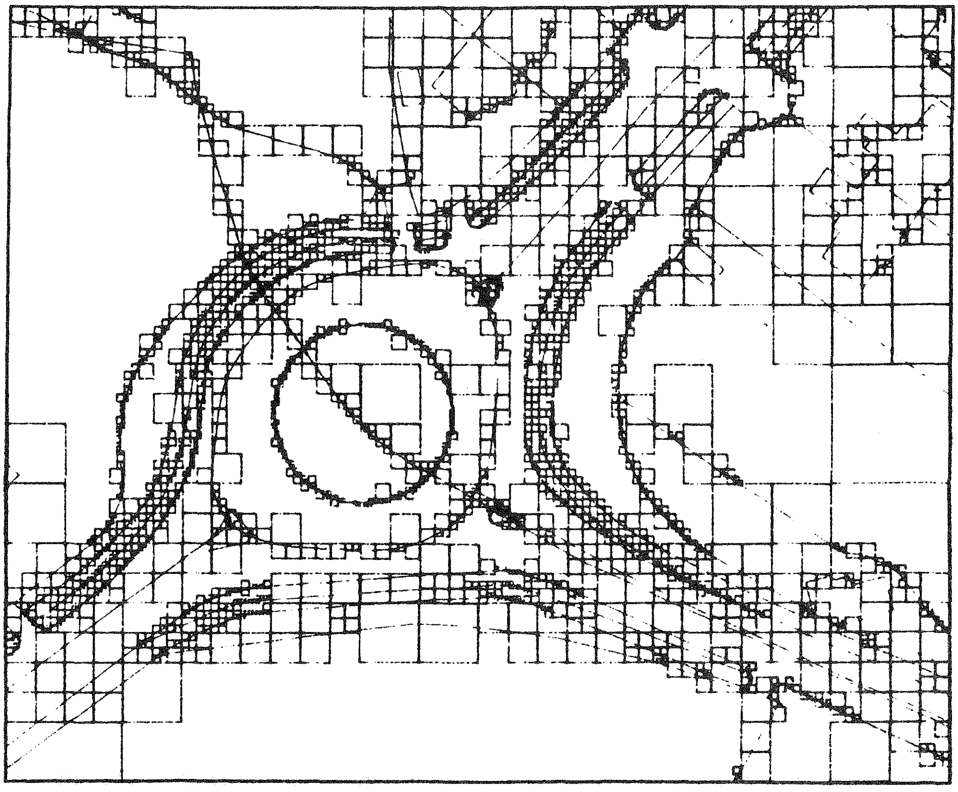


Figure 1: Visualisation of quadtree spatial index superimposed on map road features (UK map sheet 111)

which is the logical sum (the OR) of its descendant's colours.

This approach enables the efficient top-down quadtree search for features with particular characteristics; for example identifying all water features that intersect with road features.

Feature analysis

This section looks at the properties of features within a map database and SPOT satellite images.

Feature visibility

The SPOT satellite, in its sun-synchronous near-polar orbit at an altitude of 832km, has an off-nadir viewing capability. The HRV instrument can operate in panchromatic mode over a broad spectral band, producing imagery with a 10m instantaneous field of view; or 20m in multispectral mode, within 3 narrower bands. Visual inspection of the images show that the most clearly distinguishable features are:

- water bodies — which, although highly visible, are susceptible to temporal changes (such as reservoir height variation).
- roads — everywhere except through heavily urbanised areas.
- railways
- tracks and pathways — although narrow, the vegetation or other features associated with some tracks make them very visible

- field boundaries — especially where different crops are grown (although again, such features are subject to seasonal changes).

A more quantitative study [Dowman *et al* 87] has tabulated omissions from mapping produced manually from stereo SPOT imagery in Aix-en-Prevence (as compared to established 1:50,000 maps). As expected major features such as major roads and canals, rivers and railways were well represented but minor roads and canals, streams and buildings were less well mapped.

Although a simple list is of some benefit, it must be stressed that scene matching is complicated by cloud cover and by illumination and seasonal variations between images.

Manual orientation of a satellite scene to a map is usually achieved by identifying a few large linear features on each and approximately aligning them. Subsequently small modifications are made based on local area searches. This can be interpreted as a 'coarse–to–fine' matching strategy.

Interest operators [Naliva and Binford 86] are *automatic* procedures that may be applied to images to enhance particular features. (Figure 8 illustrates the application of a simple Sobel filter to a portion of SPOT imagery whose effect is to enhance edges). Features which are known to be particularly susceptible to interest operators, and exist in a map database, are then prime candidates for ground control features. Further details of this approach are reported in [Muller *et al* 88] (this conference).

Feature based statistics

Using some specially written 'macro' routines within the Laser-Scan LITES cartographic editing package, statistics have been gathered about the features within a particular map-sheet in our test area. For statistics to be meaningful, it is important that the data is structured into a 'link and node' form. Data such as length and bounding box of features give information which is used to assist selection of prominant features (see later section). Figures 2 and 3 illustrate feature statistics from a sample of UK map sheet 111.

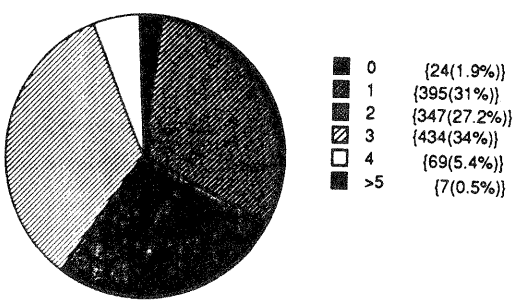


Figure 2: Number of arms at nodes within map sample(UK map sheet 111)

Quadtree based statistics

The quadtree structure described above has its nodes stored in the order that is produced by inspecting each line segment in turn. This may be thought of as a pseudo-random method of ordering the nodes in memory. A 'reforming' program reads the quadtree and produces a new version which has its nodes organised depth first. This does not significantly reduce the execution time for a single traversal of the tree, but it does reduce the number of page faults (i.e., the amount of page swapping that the operating system is required to do).

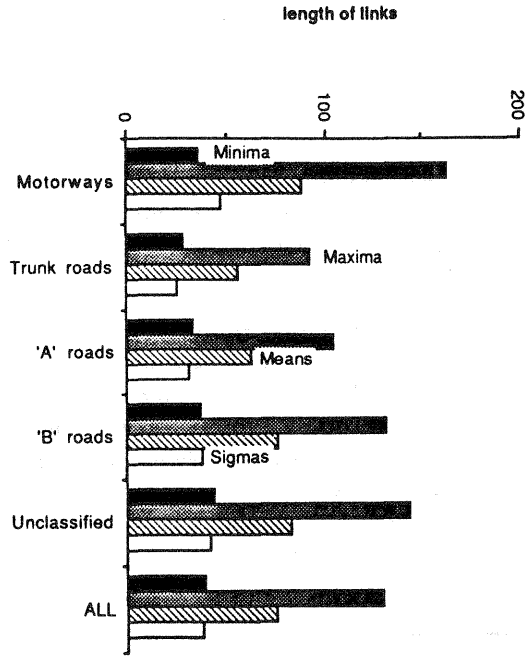


Figure 3: Statistics on link length for specified road features(UK map sheet 111)

After reforming it is a simple matter to traverse the quadtree, counting how many leaves (squares not requiring further sub-division) and how many internal nodes there are at each level. Sample statistics from a UK map sheet OS111(SW) in our test area from which a spatial index has been generated is shown in figure 4. This has been calculated for all features, but it is equally possible to pre-select individual features, such as roads. The graph contains information concerning the size of features which can be found at different levels.

Level:	Nodes	Leaves	
0:	1	0	*|
1:	4	0	*|
2:	16	0	*|
3:	64	0	*|
4:	256	0	*|
5:	969	27	****|*
6:	2704	437	*********|**
7:	4982	2619	****************|*********
8:	4766	8800	****************|*****************************
9:	2701	10370	*********|**********************************
10:	973	6446	****|*********************
11:	238	2499	*|********
12:	105	548	*|**
13:	44	270	*|*
14:	20	103	*|*
15:	8	47	*|*
16:	7	15	*|*
17:	4	17	*|*
18:	3	9	*|*
19:	2	7	*|*
20:	1	5	*|*
21:	0	4	|*

Figure 4: Statistics for quadtree of UK map 111(SW) — Graph shows distribution of nodes and leaves for all features.

Feature extraction

Extraction by window

Satellite image data is often provided with some indication of its ground coverage. The SPOT header contains the latitude and longitude of the four corners of the image. Experience within the SPOT PEPS programme (e.g. [Begni 87]) has shown this to be accurate to about 40 pixels (400 ground meters). This is very useful in providing an initial orientation.

Programs have been written to decode both the SPOT image and its header information, which is stored in a text file in a 'keyword = value' format. The data is used in two ways. Firstly, the coverage allows the correct map area to be found. In the UK test area the digital map data is stored on a map-sheet basis. Secondly, the four image corners, read from the header file (in latitude and longitude) and pixel coordinates are used to construct a least-squares 3-point (affine) transformation. This is applied to the map data to produce an initial approximate registration between map and image files (and can later be used during automated matching to restrict the search for corresponding map and image features). Figure 5 illustrates the map transformation process.

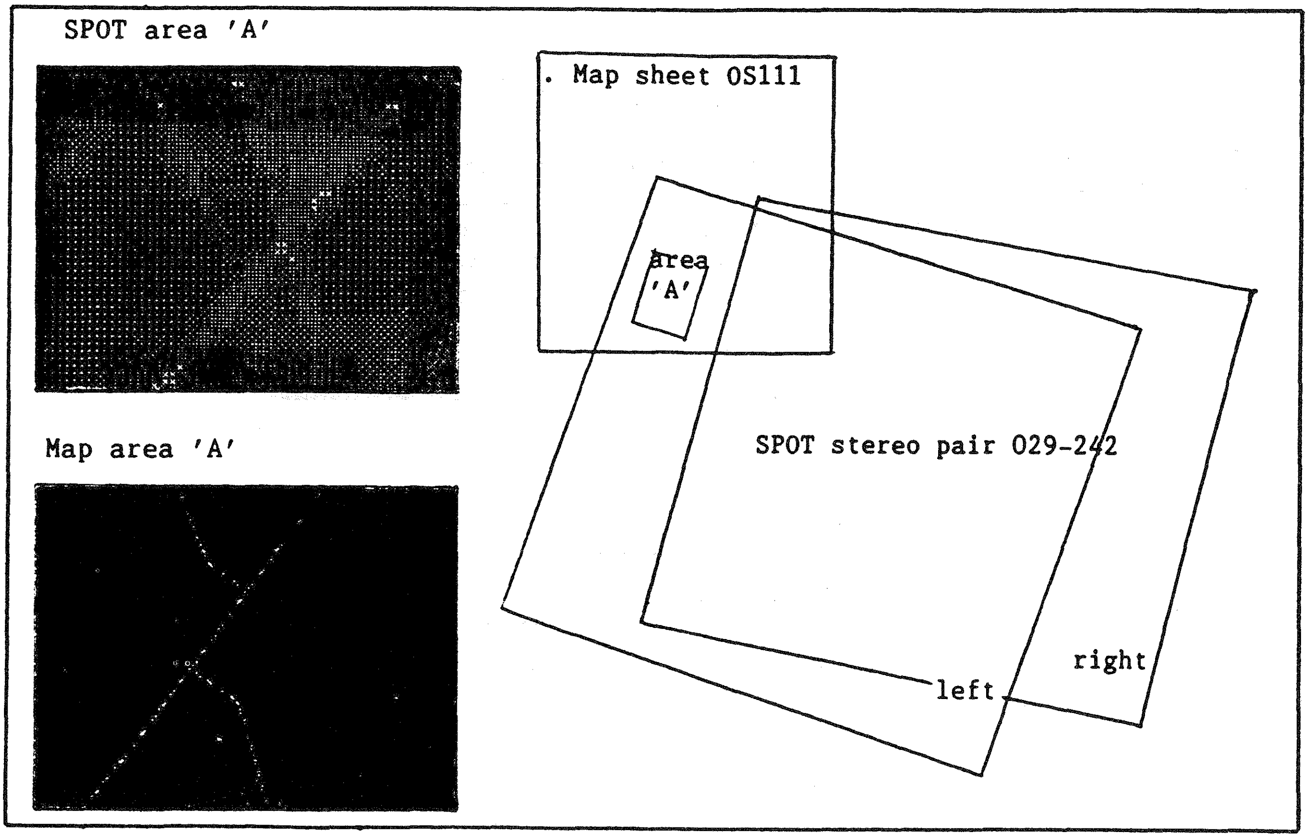


Figure 5: Initial registration of map and image by map transformation derived from orbital parameters

Extraction by 3D feature

Laser-Scan have an extensive suite of programs for the selection and manipulation of map data stored in IFF files. The ISELECT utility allows portions of the vector file to be selected on a number of criteria. These include feature code and height.

As noted above, one of the most reliable features for matching are roads. If the digital database contains 3 dimensional information about the roads, this may be directly extracted. However, many maps are held in a 'flat' form where each feature is represented by its planimetric coordinates and height has to be deduced from other information including:

- contours
- spot heights
- river and reservoir heights
- clifflines and ridgelines

[Morris *et al* 87] reported methods of processing such feature and height data to derive estimates of GCF height and accuracy. An example of road features extracted from the map database and processed into a 3D network is shown in perspective in figure 6.

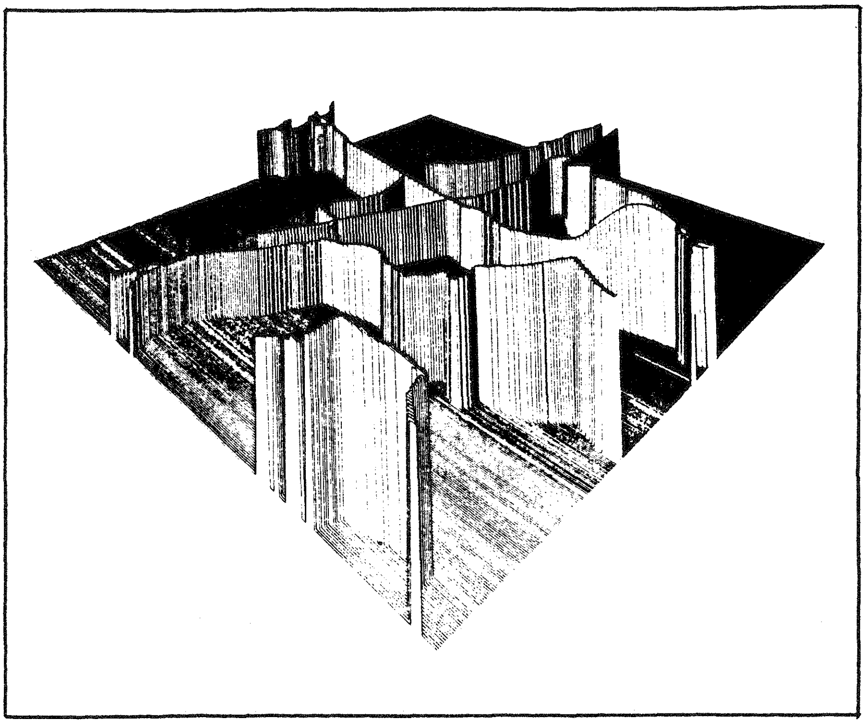


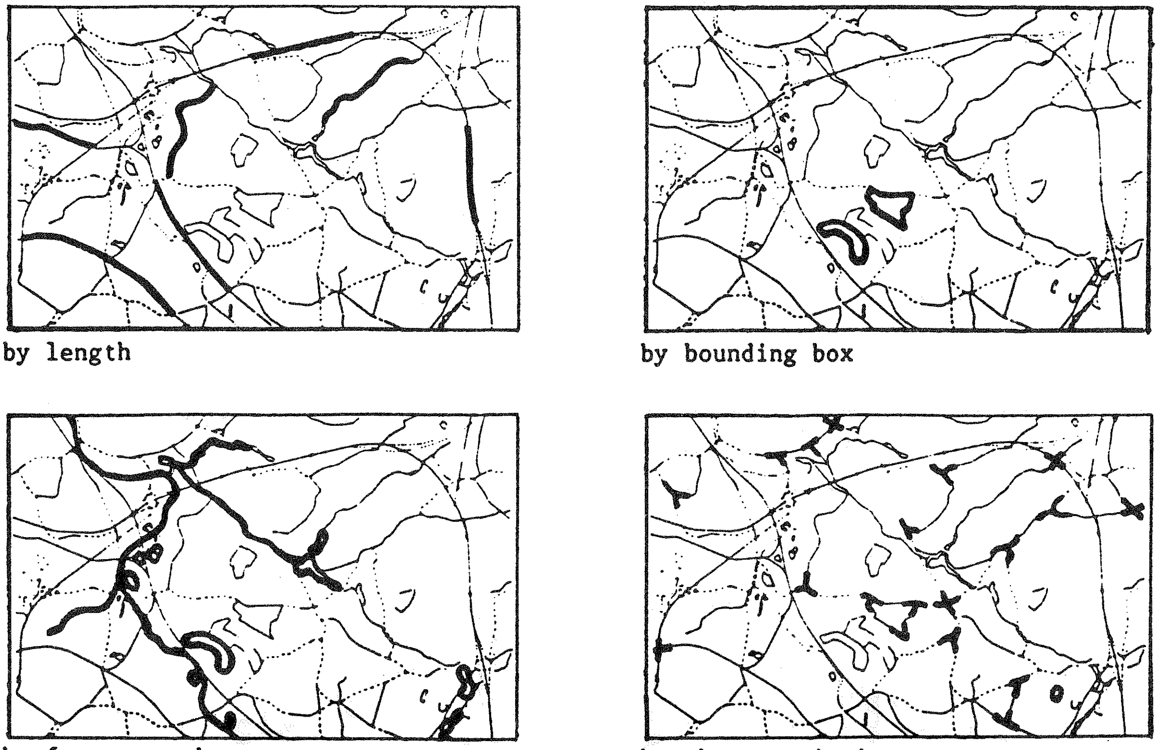
Figure 6: Perspective visualisation from West of road network from French map-sheet 3243W

Extraction by size and shape

Using the feature based statistics methods described above, features in IFF form can be extracted on size and shape criteria. Figure 7 shows an example of feature extraction from a map sheet where particular size and shape criteria have been applied. Small isolated features can most readily be distinguished in combination with the spatial index method (see below).

Extraction by spatial index

Creating a spatial index of the map area covering the SPOT image can assist feature extraction from the map in a number of ways. In particular it is useful for operations involving neighbouring points in



by length

by bounding box

by feature code

by characteristic - isolated road junctions and corners

distinct features such as in operations involving the location of combinations of features (e.g. roads over rivers).

To further explore the use of a spatial index, program was written to perform a dilation of selected features in a quadtree [Ibbs 88]. The operation is analogous to the dilation of a raster region quadtree [Mason 87]). Dilation is an intrinsically raster operation, and a pixel size parameter is thus required. (The actual pixel size used will be the largest quadsquare that is not larger in X or Y than the 'pixel' parameter, which is a floating point number). A 'radius' parameter specifies the distance by which the selected features are to be dilated. A line of (notional) zero thickness will be dilated to become twice 'radius' units thick, within a tolerance of 'pixel' units.

Potential uses of dilation include the location of small features which are particularly visible by their isolation. The technique being developed involves processing a network of features, such as roads, into a link and node structure, and determining if other features are present within the dilation radius of each node (figure 7). Dilation can also be used to amalgamate clusters of small features that are likely to be visible together in a satellite image (and has wider uses in GIS systems enabling operations such as "find all the telephone boxes within 100m of class 1 roads").

Feature Exploitation

Creating a pixel image

One method of 2D map-image matching involves the generation of a pixel image from the vector based map data. The problem then reduces to a form of image-image matching, various techniques for which have previously been addressed by a number of workers on SPOT imagery (eg [Collins *et al* 87], [Chau and Otto 87]). These techniques use interest operators (see above) to determine corresponding match points.

To generate such a pixel image from the extracted map data, a program called I2GRID is used that will transform each feature with feature code fc onto a pixel area with width $w(fc)$ pixels and pixel value $v(fc)$, for a given pixel size (figure 8).

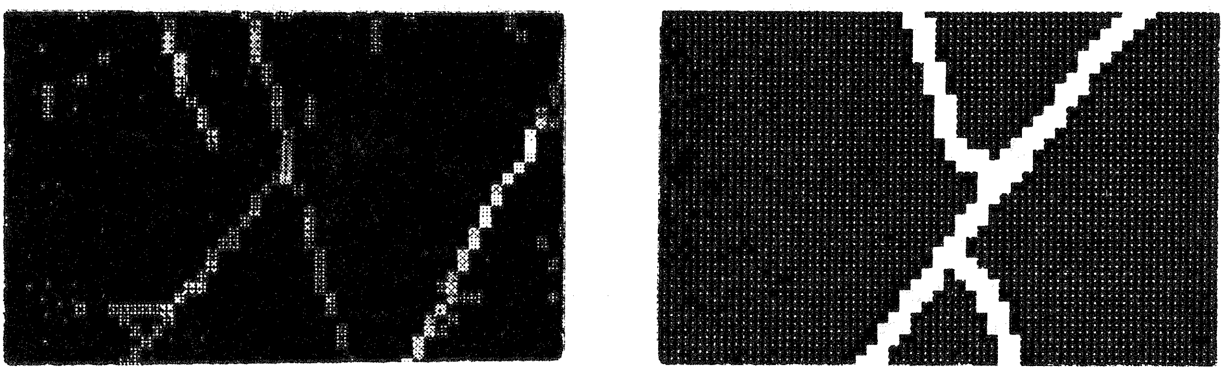


Figure 8: Edge detected SPOT image and corresponding 'gridded' map.

The development of this pixel generating software is assisting the evaluation of existing image-image matching techniques for absolute orientation. It has applications in terrain visualisation, where 2D correspondence is sufficient, for example in nadir images, and for shading of existing digital terrain models with greyscale pixel values.

Superimposing extracted features onto pixel images

Three dimensional GCFs, such as the road network shown above can be translated to SPOT image coordinates using the absolute orientation projection model. A program has been written, making use of the orientation model to project 3D map features into left or right SPOT image coordinate space, while preserved the IFF feature-based structure. Such software is now being used to assist the evaluation of automated map-image matching techniques such as dynamic programming [Maitre and Wu 87].

Computer assisted map-image matching

Software has been written to allow pixel images and map data to be displayed and manipulated simultaneously on a DEC graphics workstation. The data may be displayed in separate windows or superimposed in a single window. An operator may then point and record corresponding locations (to sub-pixel accuracy) using the workstation mouse in map and image. Such points constiture a *registration control point* file which serves as the basis for absolute orientation calculations. Techniques reported above are being used to partially automate the registration process in the following ways:

- SPOT header information is used to window into the correct map-sheet.
- Feature transformation is used to orientate the map data (progressively as registration information is built up).

- Feature extraction operations may, optionally, be used to remove unwanted or confusing data.
- Features chosen by techniques used above may be optionally highlighted for the operator (by blinking or by a change of colour).
- 3 dimensional features may be projected through the orientation model onto the image plane to check correspondence.

Summary

A number of techniques and software packages have been described to extract and manipulate feature based map data. These form part of an ongoing research programme into the exploitation of SPOT satellite imagery. Map based features, from a variety of sources, have been automatically identified using pre-set criteria and used to assist interactive map-image registration for absolute orientation. The techniques presented provide a basis from which automated map-image registration can be investigated.

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References

[Begni 87] G Begni. *Image quality - 20 months' experience* Proceedings joint Photogrammetric Society/Remote Sensing Society one day symposium on 'Results of preliminary evaluation programme for SPOT'. London November 1987.

[Chau and Otto 87] T K W Chau, G P Otto. *Design and implementation notes for UCL-CS's Gruen's stereo matching algorithm* Alvey MMI-137 internal report 17 1987.

[Collins *et al* 87] K A Collins, J B G Roberts, A Anthony, J-P Muller. *Transputer arrays for real-time feature point stereo matching* Presented at ISPRS Intercommission conference on Fast Processing of Photogrammetric Data. Interlaken, Switzerland 2-4 June 1987.

[Dowman *et al* 87] I J Dowman, D J Gugan, J-P Muller, G Peacegood. *The use of SPOT data for mapping and DEM production.* SPOT1 International colloquium. Paris France November 23-27. 1987.

[Gahegan and Hogg 86] M Gahegan and J Hogg, 1986, *A pilot geographical information system based on linear quadtrees and a relational database for regional analysis.* Spatial Data Processing using Tesseral Methods (collected papers from workshops one and two), edited by Diaz and Bell, NERC Unit for Thematic Information Systems, 213-321.

[Green and Rhind 86] N P Green and D W Rhind, 1986, *Spatial data structures for geographic information systems.* Report no. 2 of Conceptual design of a geographic information system for the Natural Environment Research Council, a NERC Remote Sensing Special Topic.

[Gugan 87] D. Gugan *Practical aspects of topographic mapping from SPOT imagery* Photogrammetric Record vol 12(69), April 1987, pages 349–355

[Hartnall *et al* 86] T J Hartnall et al, 1986 *IFF user guide, part of the MAPPING package documentation.* Laser-Scan Laboratories Ltd, Cambridge, England.

[Ibbs 88] T J Ibbs *QUADIFF report number 2* Alvey MMI-137 internal report 1988.

[Ibbs and Stevens 87] T. J. Ibbs and A. Stevens *Quadtree storage of Vector data for Geographic Information Systems* Presented at: GIS-LP '87—International Conference on Geographic Information Systems for Land Planning, Lisbon, 14–18 September 1987

[Jackson *et al* 88] M. J. Jackson, W. J. James, A. Stevens *The design of environmental Geographic information systems* Royal Society — in press.

[Jackson and Mason 86] M J Jackson and D C Mason, 1986, *The development of integrated geo-information systems.* International Journal of Remote Sensing,7, 6, 723-740.

[Maitre and Wu 87] H Maitre and Y Wu. *Improving dynamic programming to solve image registration.* Pattern Recognition Vol 20 No 4, pp. 443-462 1987.

[Mark and Lazon 84] D M Mark and J P Lazon, 1984, *Linear quadtrees for geographic information systems.* Proceedings of the International Symposium on Spatial Data Handling, Zurich, Switzerland, 412-430.

[Mason 87] D. C. Mason *Dilation algorithm for a linear quadtree* Image and vision computing, vol 5 no 1, February 1987, pages 11–20

[Morris *et al* 87] A C Morris, A Stevens, J-P Muller. *Ground control determination for registration of satellite imagery using digital map data* Presented at 'Results of preliminary evaluation programme for SPOT'. London November 1987 and Photogrammetric Record (in press).

[Muller *et al* 88] J-P Muller, N Dalton, D Gugan, A C Morris, G Peacegood, A Stevens. *Map-image registration and automated image feature extraction* ISPRS Commission II. (this conference).

[NTF] NTF , 1987, Working party to produce national standards for the transfer of digital map data "National Transfer Format". Produced by Ordnance Survey (GB) on behalf of the working party. Release 1.0.

[Naliva and Binford 86] V S Naliva, T O Binford. *On detecting edges* IEEE Trans PAM I -8(6) pp. 699-714 November 1986.

[OSTF] OSTF, Ordnance Survey (GB) - definition of the OS transfer format, OSTF.

[Samet and Webber 85] H Samet and R E Webber, 1985, *Storing a collection of polygons using quadtrees.* ACM Transactions on Graphics,4, 3, pp.182-222.

[Samet *et al* 85] H Samet, A Rosenfeld, C A Shaffer, R C Nelson, Y Huang and K Fujimura, 1985, *Application of hierarchical data structures to geographical information systems: Phase IV.* University of Maryland, USA, Computer Science Technical Report CS-TR-1578.

[Waugh 86] T C Waugh, 1986, *A response to recent papers and articles on the use of quadtrees for geographic information systems.* Proceedings of the Second International Symposium on Spatial Data Handling, Seattle, USA, 33-37.