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AUTOMATED PROCEDURES FOR INTEGRATION OF SATELLITE IMAGES AND MAP DATA FOR CHANGE DETECTION: THE ARCHANGEL PROJECT.

Ian Dowman

University College London
United Kingdom

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ABSTRACT

The need for automation in the registration of image to image and image to map is widely recognised and work has been going on for some time in both the photogrammetric and remote sensing disciplines. For large scale aerial photography the automation of absolute orientation is tied in with feature recognition but for satellite data operations can take place at a lower level and the problem of relief displacement and occlusions is less. The image to image registration problem is some way to being solved but the image to map problem is much more difficult. The main bottleneck is the identification of points which can be seen on an image and on the corresponding map. This is a manual task at present requiring a considerable amount of time. It is particularly difficult in areas where there is little cultural development and where poor, out of date maps are the only ones available. The ARCHANGEL project is designed to develop a system for the automatic registration of satellite data to maps and this paper describes the system developed and the some of the results achieved.

A second difficult and tedious task is the identification of areas where change has taken place. The job of the skilled interpreter is to determine the nature of change, s/he does not wish to spend time finding where the change has occurred. The key aspect of the project is therefore to develop a method which will automatically find common points on the maps and images in any type of area and which will also find areas where change has occurred.

The paper will describe the algorithms which have been developed and tested and integrated into a prototype system in an environment called XPECT, developed by Earth Observation Sciences Ltd. Results to date show that the basic algorithms give good results for segmentation, map processing and matching. The algorithms have been tested by the developers and the overall system will be tested by Swedish Space Corporation as end users.

1 INTRODUCTION

Currently there are several high profile European programmes, initiatives and studies that are attempting to address the effective exploitation and utilisation of remote sensed data. Attempts are being made to provide a coherent ground segment and user services infrastructure, enabling and support technologies, exploratory thematic activities and application service demonstrators. The ability to effectively register and fuse Earth observation data from heterogeneous sources, such as SPOT and ERS, is of paramount importance. Similarly, the ability to extend this capability to include maps and other sources of data is essential. As is the need to provide information products in a user-friendly format. This is the main focus and objective of the project which is funded by The European Commission, within the 4th Framework, to develop a system to automatically carry out registration of satellite images with maps known as ARCHANGEL (Automatic Registration and CHANGE Location).

The general objectives of the project are:

- develop and implement, in prototype, a system for automatic registration of optical and microwave images, derived from space borne sensors, with each other and with vector data;
- develop algorithms to detect change in the registered image and implement these in an environment which allows fusion of image data and geographical information in vector format (GIS);
- provide the facility for application scientists to detect change of a particular type specified by them.

The consortium carrying out the projects comprises University College London (UCL); Earth Observation Sciences (EOS); Institute for Photogrammetry, University of Stuttgart (IfP); Royal Institute of Technology, Stockholm (KTH); University of Oporto (UO); Swedish Space Corporation (SSC). The project is building on work done by the partners, in particular by UCL, Stuttgart, Oporto and EOS on the PAIRS project which has been concerned with automatic registration of images. Work on this project has been going on for some years and now includes modules for registration of SPOT data with SPOT data, creation of DEMs from SPOT and similar optical data and is currently developing similar modules for SAR data. Some of the modules from PAIRS have been imported directly into ARCHANGEL. KTH have been brought into the project for their expertise on feature extraction and change detection and SSC are involved because of their experience with production of image maps and other value added projects which could involve automated registration.

This paper gives brief description of each component of the system and then gives selected results.

2 OUTLINE OF THE COMPLETE SYSTEM

2.1 Overview

The project is broken down into three phases: System design, algorithm development and evaluation. The components are shown in figure 1.

2.2 Detection of cloud, snow and ice

The objectives are to define algorithms for the automatic detection of cloud, snow and ice on satellite images and to mask out unusable areas and define region of interest.

Three different approaches were implemented and applied to test cases involving SPOT panchromatic and LANDSAT-TM imagery. It was determined that a fully automated scheme would not work with the range of cloud types, particularly thin cirrus and contrails, which are likely to be present in high resolution satellite images with limited spectral information. An interactive semi-automated scheme was therefore implemented as a XPECT process. This interactive process expects the user to indicate by means of placing a box cursor over those regions which the user identifies as cloud, shadow and snow/ice in order to determine the local thresholds to be used within an extremal region-growing segmentation.

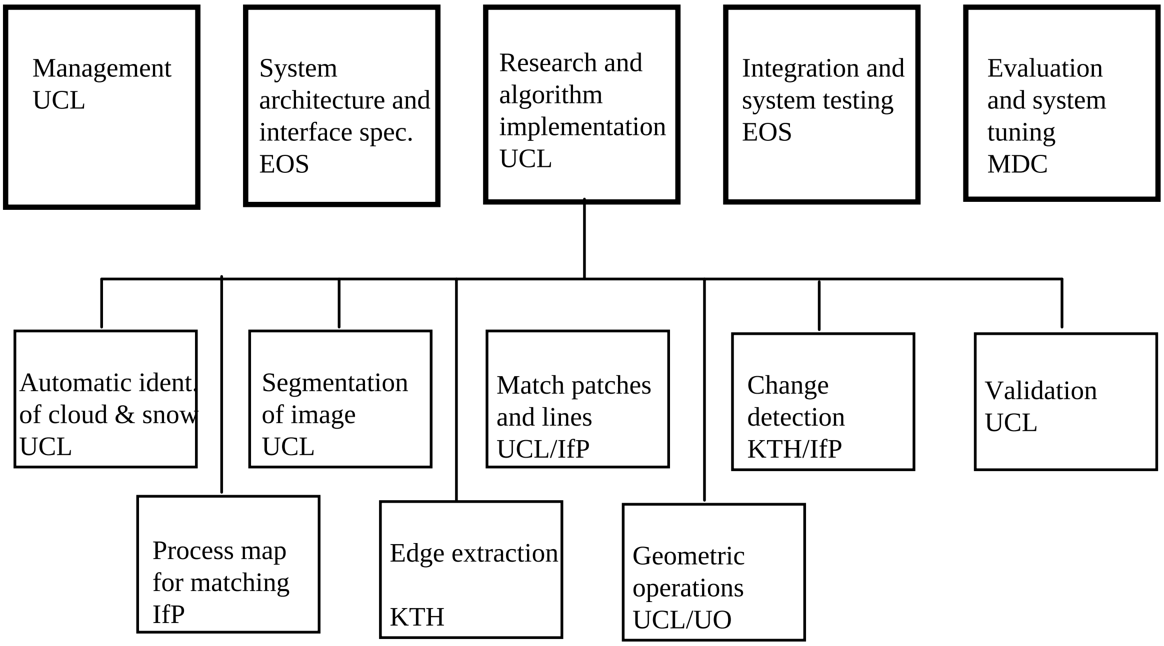

Figure 1. Components of the ARCHANGEL project.

The algorithms developed are incorporated into an environment developed by EOS called XPECT as modules in the process library. These can be assembled on the screen using the XPECT GUI to form processing chains known as models. Models can be stored in the model library and can be implemented from the GUI.

An example of a model is shown in figure 2. This shows the processing chain to generate corresponding points between a SPOT image and a map and the components of this are discussed in sections 2.3, 2.4 and 2.6.

Each of the main development modules are summarised below.

2.3 Map Processing

A key component of the system is the input of the map data and the processing of this to allow matching. This broke down into two main aspects:

- algorithms to extract relevant layers from vector data sets which can be matched with features extracted from images.
- algorithms which extract relevant features from raster data which can be matched with features extracted from images.

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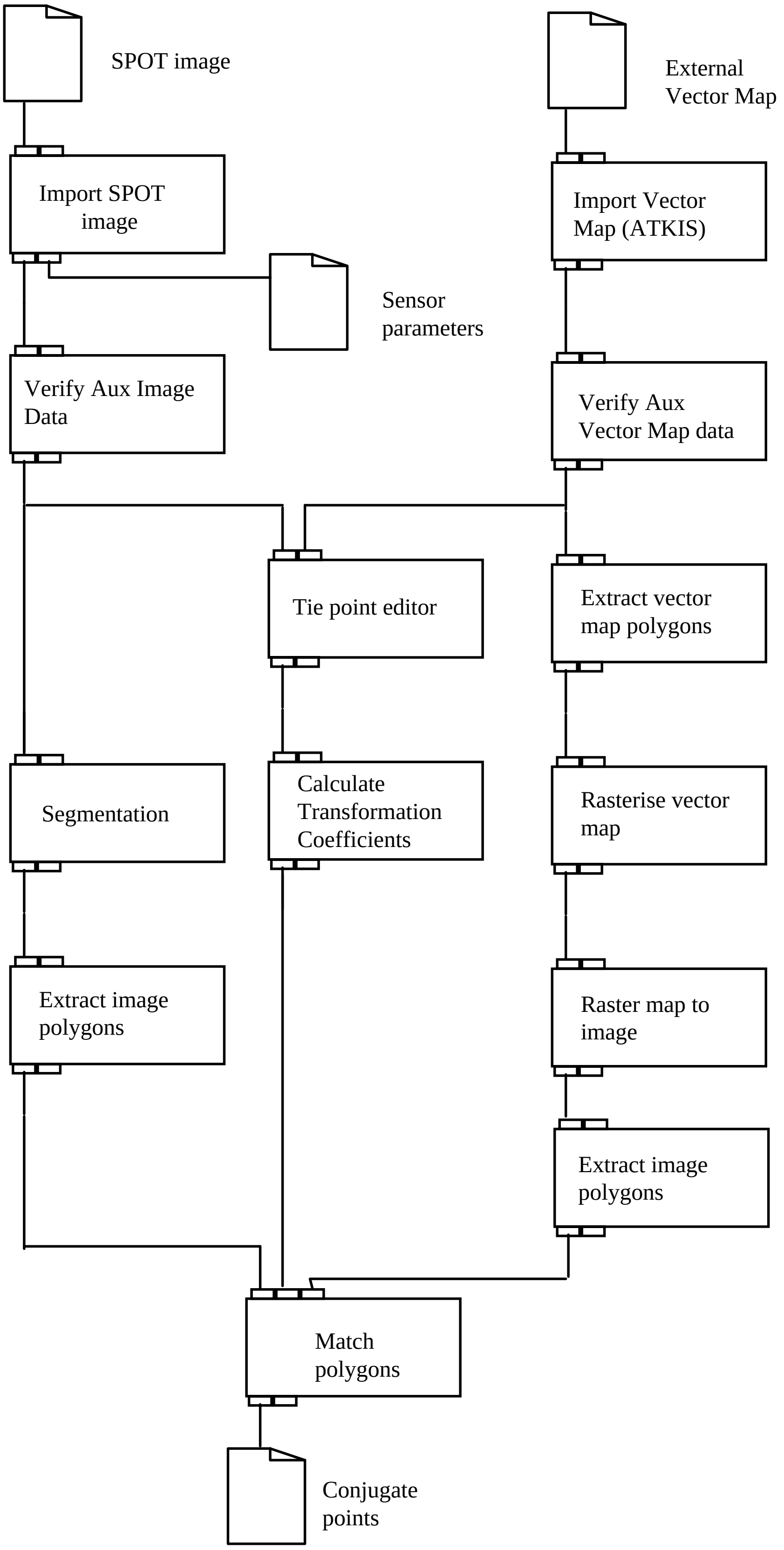


Figure 2.: The model within XPECT which derives conjugate points from a SPOT image and a map. The left hand processes extract ploygons from the image and the right hand from the map. The Tie point editor allows an initial approximate orientation to be checked and modified if necessary.

These have been implemented as follows:

- Introduction of classes to the format.
- Algorithms to "Import ATKIS Data", "Extract Vector Map Polygons", "Rasterise Vector Map" and "Rasterise Vector Map Linear Features".
- Refinement of "Extract Vector Map Polygons" by adding the possibility to extract only polygons of a desired area range.
- Develop GeoTIFF, the internal Raster Map format.

This work had to exploit and take maximum advantage of object-wise stored topographic data offered by country-wide topographic data bases (e.g. German ATKIS, French BDTOPO, etc.) and to match single map features with features represented in optical imagery (e.g. SPOT, Landsat TM, etc.). Even though it may seem simple to extract digitally stored topographic data, it becomes clear that every national vector data set is stored its own data format. Thus, huge efforts had to concentrate on the definition of a common data format for vector and raster data to be used in the ARCHANGEL team.

The chosen solution is an internal format called IfP-format for vectorial data sets and the GeoTIFF format for raster data. Several algorithms have been implemented to extract vector map polygons, to rasterise vector maps, and to rasterise vector map linear features . A re-judgement of these implementations gives a good sign for having chosen the right strategies for all team members. The work is described by Hild and Fritsch (1998).

The data flow for extraction of vector map polygons is shown in figure 3.

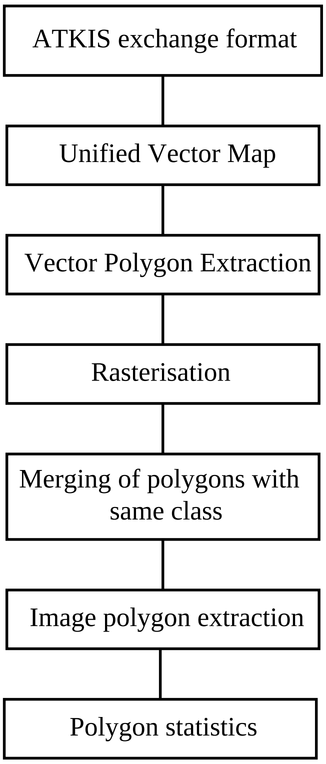


Figure 3. data flow for the extraction of vector polygons from ATKIS data. (After Hild and Fritsch 1998)

2.4 Segmentation

The extraction of polygons from the images was carried out by segmentation with the objective of defining homogeneous patches in an image which can be registered with corresponding features in an reference data set. Separate algorithms are required for electro optical imagery and microwave imagery

This work had to exploit and take maximum advantage of the different types of inputs: optical, microwave and topographic data . Even though primary studies claimed that the design of a segmentation specific to an image type was not the best solution, we have modified our judgement. The chosen solution is an adaptation of the processing either to optical data or to SAR images.

Thus, 2 algorithms have been implemented. The optical data processor is called *REGSEG_97* and the radar image processor *CoCo*. The method is described in more detail in Ruskoné and Dowman (1997).

The optical segmentation algorithm characteristics are as follows:

- region growing algorithm exploiting the statistical properties of homogeneous regions followed by a region merging;
- optional use of edge information that may come from maps of from masks defined by any other work packages;
- ability to use the region space (instead of the image one) for a efficient and fast merging procedure;
- iterative merging procedure (allowing the propagation of the merging to several neighbouring regions).

A different algorithm has been implemented for the processing of radar image given the level of speckle of these images. The level of heterogeneity of the regions likely to be identified in the SAR data is so important that only the most obvious objects can be identified. These objects can be characterised either by their extremely bright radiometry (iron bridges, factory roofs, etc.) or, on the contrary, by their very dark grey levels (mainly water areas). The segmentation algorithm is called CoCo (that stands for Connex Component segmentation); its characteristics are as follows:

- seeded region growing algorithm relying on very simple radiometric characteristics;

- optional use of edge information.

The segmentation algorithms appear to give good results when judged by themselves but for ARCHANGEL well defined features are required which can be matched with map data. For this reason it was considered desirable to further filter the data and to create a registrability measure. To do this a model was designed which involves:

- the implementation of filtering procedures to select only the most relevant and reliable objects,
- the distribution assessment of the filtering criteria according to the reliability of the objects,
- the modelization of this distribution (fuzzy logic or statistics),
- the labelling of each pixel of the segmented image according to its "registrability index".

This concept was implemented with satisfactory results.

2.5 Edge extraction

The use of polygons is supplemented by the use of linear information which can be extracted from maps in the form of features such as the road network. Algorithms have been developed for extracting road intersections from electro optical imagery, which can be used for matching with corresponding features in reference data set. See Klang (1997).

This work focuses on road intersections being an optimal combination of geometrical and radiometric characteristics in high resolution satellite images. Topographical maps and data bases include geometrical errors due to cartographic adjustments. In data base nodes, e.g. intersections of the road network, these negative effects are reduced, forced by quality demands from road administrations. Statistics from 10 years production of high resolution satellite imagery at SSC Satellitbild indicate that approximately 70 % of the archived control points are road intersections verifying the relevance in the suggested object choice.

The objective is extraction of salient road intersections without any use of existing data bases. The result is intended to be used in a later matching procedure between data base and un-corrected image data.

2.6 Patch/Line Matching

The matching is the key issue in the system and as indicated above the solution adopted is to match polygons and road intersections from images with maps.

The basic techniques which are used are the extraction of line and area features from image and map and then the matching of these features. The polygon is the main feature used. These are extracted from vector data by selecting features with an appropriate attribute, for example lakes, forests or field boundaries. The polygons are extracted from the images by segmentation which is refined by applying a registrability index to eliminate polygons which are unlikely to give a match.

The basic techniques of matching polygons is adapted from Abbasi-Dezfouli and Freeman, (1994). Polygons are characterised by a number of parameters such as shape and area. Shape is defined by a bounding rectangle, parallel to defined axes, and also by the chain code method described by Abbasi-Dezfouli and Freeman. The initial translation and azimuth must be fixed by first defining a few polygons which have good matches based on a first pass through the selected points. An iterative approach then allows corresponding polygons to be identified. A large number of polygons are not necessary but it is important that they are distributed in a suitable pattern over the image.

Once established the corresponding polygons must then be exactly matched in order to extract conjugate points. A method of dynamic programming developed at UCL is one method of doing this, (Newton et al, 1994). The perimeter of the feature is followed and a best fit obtained. Costs are determined by a number of measures relating the predicted edge pixel position projected into the map and the edge pixel under consideration. The difference in gradient direction between the map boundary pixel and the edge pixel under consideration are also used as costs. The method also allows the detection of changes between the two polygons which may represent true change or an error in detection, in either case such points will not be selected as conjugate. The technique makes allowance for the fact that the image may be distorted due to terrain effects or geometric effects from the camera or sensor.

Road intersections extracted from the image and the map can be matched by intensity matching. It is necessary to have good initial estimates for this and the process may be used to complement the polygon matching. It would be possible to use relational matching if the road intersections were converted to vector data.

2.7 Geometric operations

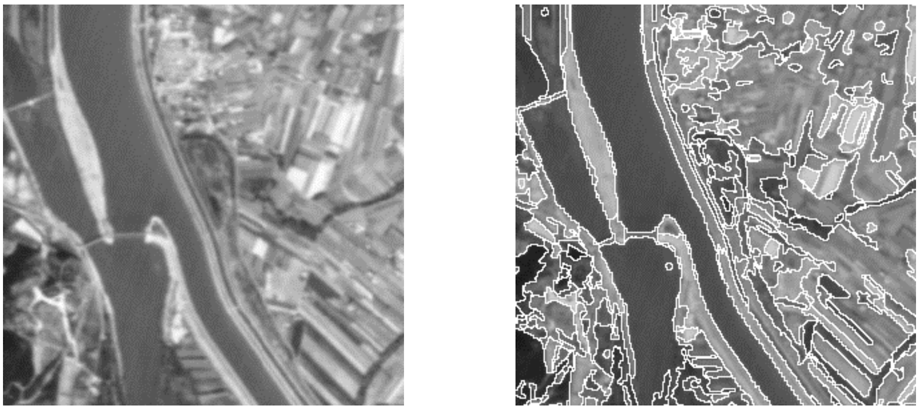
The feature extraction and matching is performed before any geometric correction has taken place, hence distortion due to orientation and terrain are still present. A number of tools have been developed to correct for these distortion. These include:

- Transform image to reference data in 2D;
- Compute orientation for single images (space resection);
- Determine Z co-ordinate of corresponding points from DEM;
- Produce orthoimage from EO and SAR data

The sensor model, was developed and tested for the orientation of airborne and spaceborne imagery. This algorithm outputs the orientation and internal parameters of the sensor or sensors platforms and cameras defining their geometry and position and attitude in space. A physical approach was adopted. The Euler orbital parameters plus a linear approach for the variation of the attitude with time were used for the spaceborne sensors. The model is applied to both across and along track linear array imagery. The orientation of perspective camera photographs is done simultaneously with any other sensor data, using a central perspective reconstruction of rays in space.

2.8 Change Detection

The objectives of this part of the project was to develop algorithms for detecting change in registered images or registered image and map. KTH worked on detecting changes in objects, particularly roads, using grey level comparisons [Klang 1998]. Two procedures for change detection are being developed and implemented. The first one uses the information present in a data base to identify corresponding objects in an image and then compare the detailed geometry as given by the data base and image. The second procedure compares two images pixel by pixel after having performed a normalising grey level transformation and noise reduction.



SPOT panchromatic subscene

Segmented region edges on original image

Figure 4. An example of SPOT segmentation.

2.9 Validation

It is essential that tools for validating image registration and change detection are included. The validation of automated geocoding can be performed in three ways:

- Manual geocoding could be performed by the end user using a commercial off-the-shelf (COTS) package.
- Visual comparison using a flicker system.
- By geocoding a number of images over the same area and then using the previously developed automated image-to-image registration system.

Algorithms to carry out these operations will be included.

3 RESULTS

3.1 Results of segmentation

The expected results of the segmentation have been confirmed, especially with the use of much more constrained segmentation parameters. As in the previous version, it leads to a significant over segmentation but this drawback is controlled by the improved merging phase. The results are still mediocre for urban and forest areas because of the over segmentation due to the region model (PDF supposed to be more or less Gaussian) used during the segmentation. These areas show a very jagged aspect that is quite characteristic and which could be an excellent way to identify them and to remedy this problem. An example of a segmented SPOT image is shown in figure 4.

The following conclusions can be drawn from this part of the project:

- the segmentation toolbox allows the processing of any input images that this project had to handle (aerial, SPOT, SAR) with satisfying results;
- the future work involves the use of automatic filters grounded on a new and original measurement: the registrability index;
- the best kind of object for matching seems to be the region boundaries (or a sub-portion of these edges) rather than points or patches.

Robust, flexible segmentation algorithms have been developed and tested. These will be used with the matching algorithms to provide the key image processing algorithms for the matching process.

3.2 Results of edge extraction

The algorithm has been developed at KTH for detection and delineation of salient road intersections in high resolution satellite images. The processing result, shown in table 1, indicates 4 and 5 intersections in SPOT and IRS-1C respectively, while the limited registration resolution in Landsat effects the result of that sensor. Correction model demands are fulfilled as an extrapolation of the result indicates approximately (6000 / 500)2 * 3 = 432 intersections in one SPOT image. This is good enough for orbital as well as polynomial modelling.

	Data base points	Detected points
Landsat	0	0
SPOT	3	4
IRS-1C	3	4

Table 1. Results from extraction of road intersections from a 5 x 5km test area.

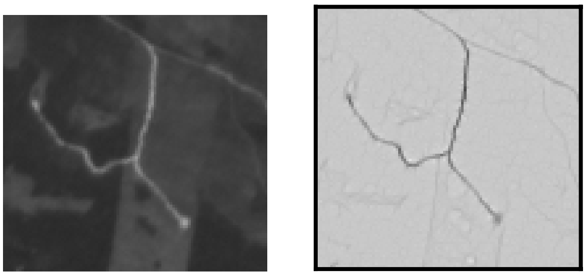


Figure 5. Examples of a road intersection extracted from SPOT data. (After Klang, 1997)

Edge extraction algorithms have been developed which concentrating on roads, since these are dominant features in a large number areas and are recognised as being good features to be used as tie points. The key features of these can be summarised as follows.

- 2-D Gaussian filtering combined with eigenvalue and eigenvector calculation fulfil the demand of robustness that is necessary in all automation processes.
- The final selection of road intersections is simplified due to the road width of one single pixel. No thinning procedure with influences on the line geometry is needed. The intersecting lines are tested against an acceptance criterion. The result includes lines relevant for the later matching process.
- Most of the initial presented road characteristics, geometrical as well as radiometric and topological are used as definitions and demands in the intersection extraction process. Geometry aspects like constant width, image resolution and changes in directions are handled by using a knowledge based approach. Radiometry aspects have been taken into consideration in the initial selection of this approach while the topology described by the network is used in the extraction of intersection points.
- Ranked averages of eigenvalues, are presented as a quality estimate of selected intersections. Geographical positions are calculated after the matching and warping procedures.

Salient intersection extraction is less time consuming compared to matching against all data base intersections. A negative effect is that salient intersections are often new roads, not existing in the geographical data base.

3.3 Matching

IfP (Hild and Fritsch, 1998) have demonstrated the full process of polygon extraction from a SPOT image and from ATKIS data and 43 well distributed conjugate points from a sub scene of 10 x 10km were automatically selected. This demonstrates that the concept of polygon matching between images and maps works well in the agricultural terrain of Southern Germany. Other tests of polygon extraction in areas of France and Spain have demonstrated that water features make good features for matching. Work is now proceeding on more testing of the matching for both polygons and road intersection.

3.4 Geometric Correction

The development of sensor models for the optical sensors is complete but that for the SAR has yet to be implemented into XPECT. Additional algorithms for transformation have been identified but not yet implemented.

4.0 DISCUSSION

Whatever the final conclusions regarding the degree of automation, the project has developed a set of useful tools for registration of images with maps and these will be valuable within an operational environment. The use of the XPECT environment has proved to be extremely valuable for development and application of this type of system and has great potential for further work.

It will be necessary to test that system and to determine its weakness and limitations and to remedy these as far as resources in the project allow. The system will be tested in an application environment by the Centre for Environmental Data in Kiruna (SSC) to determine its suitability for operational work.

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