AUTOMATIC REGISTRATION OF IMAGES TO MAPS – THE ARCHANGEL AND ARMIES SYSTEMS

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ABSTRACT

In every part of the world the rate of map revision is alarmingly low when compared to the rate of change of many human influenced surface features. There is therefore a requirement to regularly gather up-to-date information about surface features and to incorporate changes in maps both quickly and efficiently, before it becomes history. This is a need in many disciplines. The requirement for map revision can be fulfilled by developing automatic systems, the automation of map-image registration and then of change detection. At present no system is available which fully automates the task of map revision. The present paper looks into the processes involved to automate the map-image registration system.

For map-image registration the main bottleneck is the identification of points, which can be seen on an image and on the corresponding map. This paper presents two methods of automatic registration of images to maps – the ARCHANGEL (Automatic Registration and CHANGE Location) project and the ARMIES (Automatic Registration of Map to Image Evaluation Software) systems. ARCHANGEL has been implemented and tested and shown to give good registration accuracy. This system has developed a method for registering satellite data such as SPOT and ERS SAR with vector or raster map data, using polygons extracted from the two data sets. A parallel project – ARMIES - has developed a fast and an accurate solution to register high resolution satellite images to maps where height displacement can cause errors. This system is also based on automatic extraction of polygonal features. The polygonal features are considered because they have a distinctive shape and, moreover, they are extracted easily from vector as well as raster data. The paper first summaries the method and results of ARCHANGEL and then describes, in detail, the components of ARMIES system and their results.

1 INTRODUCTION

The demand for automation of map-image registration is widely recognized in many disciplines such as agriculture, town planning, map-making, disaster prone study areas and many more. These field areas need current up-to-date maps to find solutions to their problems. Work has been going on for some time in the photogrammetric as well as in the remote sensing disciplines and has been comprehensively reviewed by Heipke (1997). Heipke has stated that a generic and fully automatic map-image registration system has not yet been developed. The main problem lies with the automatic extraction of control information from images, i.e. finding a set of common points on the map and on the image automatically. Smith and Park (1999) have also realized the same problem to automate map-image registration. It seems a proper design of a strategy is required which needs to be discussed in detail. Dowman and Dare (1999) discussed the use of the term automated as applied to map-image registration: whether the system should be fully automated – which might produce incorrect end results, or to have minimum automation in terms of human interaction to gain better results. This aspect is also discussed in the present paper.

Two systems of map-image registration are discussed in this paper and both are based on automatic extraction of areal features. Both systems involve various processes: image smoothing, image segmentation by region growing technique, selection of well segmented regions, removal of clutter information, shape matching of map-image polygons and matching boundary pixels of map-image polygons to extract a set of common points for map-image registration with precision. In Section 2 of this paper the ARCHANGEL system is discussed, which summarizes the method used and the outcome of results. Section 3 describes the strategy developed for the ARMIES system. The implementation of the strategy on a SPOT image and the corresponding map is shown in Section 4 including discussions. Concluding remarks and limitations of the systems are given in Section 5.

2 THE ARCHANGEL PROJECT

2.1 Background

The European Union Fourth Framework Environment and Climate Programme funded the ARCHANGEL project. The need to effectively register and fuse Earth observation data from various sources and to provide information products in a user-friendly environment is of paramount importance. This project has mainly focused to develop a system to automatically carry out registration of satellite images of heterogeneous sources, such as SPOT and ERS, with maps. The project has been carried out with 6 partners: University College London (UCL); University of Stuttgart (IfP); Royal Institute of Technology, Stockholm (KTH); University of Oporto (UO); Earth Observation Sciences (EOS); Swedish Space Corporation (SSC). An overview of the project is given in Dowman (1998).

The main components of the project are briefly described.

2.2 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.

This work had to exploit and take maximum advantage of object-oriented 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 vector 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. The work is described by Hild and Fritsch (1998).

2.3 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 method is described in more detail in Ruskoné and Dowman (1997).

2.4 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 a 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.

2.5 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.

2.6 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.

2.7 Change Detection

The objectives of this part of the project were 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.

2.8 Conclusions and discussion

The ARCHANGEL project demonstrated that a complete system for registration of images from satellite sensors with maps can be successfully constructed and that the use of patches, or polygons, and point extracted from the boudaries of those polygons, provides a sufficient number of tie points to allow registration. The ARCHANGEL project did not implement algorithms for geometric correction and hence the final results were subject to errors due to terrain relief. Although designed as an automatic system, human intervention is necessary to select parameters and to carry out validation. Subsequent work reported by Dowman and Dare (1999) has improved some of the techniques used in ARCHANGEL. The ARMIES system takes relevant algorithms from ARCHANGEL and uses them in a system which depends on initial manual selection of polygons, matching and then elimination of points displaced by elevation effects, thus removing the need for 3D geometric correction in limited areas.

3 THE ARMIES PROJECT

3.1 Background and Objectives

Many countries do not have object-oriented country-wise topographic databases to exploit the data for map revision. However, the map data in raster format is widely available and can be used instead. The purpose of the project was to develop a map-image registration system that can be used in every part of the world and not only for the developed countries. In this project digital maps and images in raster format were used to develop the system - ARMIES.

The ARMIES project was conducted in the course of PhD research study (Vohra, 1999) at University College London and the main objectives of the project were:

- to develop a map-image registration system which has a minimum interaction of the user, and
- to develop a method to eliminate large errors for precise map-image registration.

3.2 Overview of Methodology

The project has developed a method to register images and maps with precision by removing the errors caused by relief objects without rigorous orthorectification. This removes the need for a DEM and is designed to obtain a good local fit with the effect of buildings also removed. Relief objects show perspective distortion in high resolution images and that causes errors in registering images with maps. The method developed includes a component that removes large errors before the registration takes place.

The ARMIES system consists of four modules. The modules are: preparation, matching, error elimination and registration. The intervention of the user is kept to minimum and is required for the first module only. The user is needed only to select a few desirable areal features (well distributed) from the displayed map and image on a computer. The processes and techniques involved for each module are shown in Figure 1.

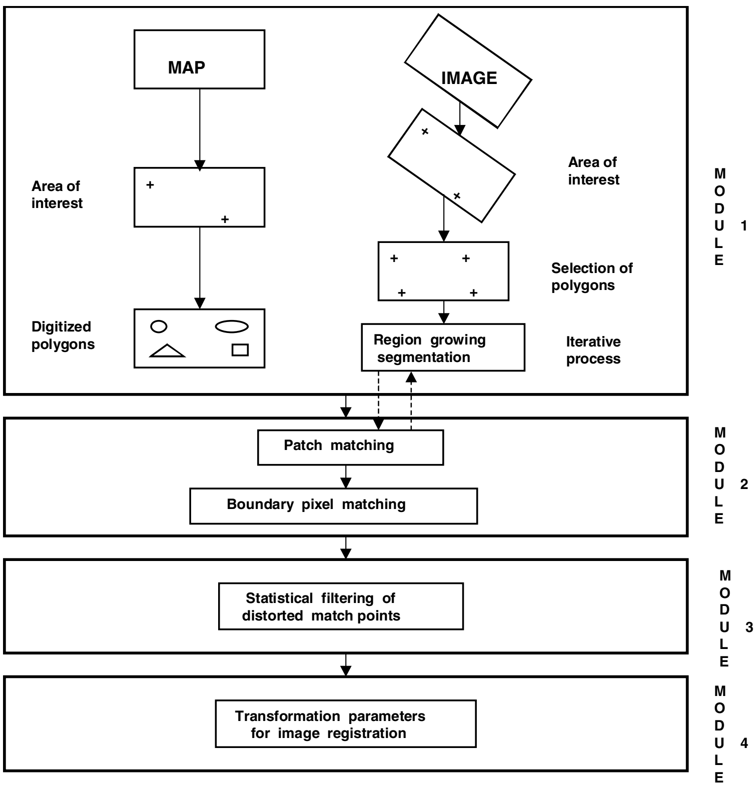

Figure 1: The ARMIES system for automatic map-image registration.

3.2.1 Preparation Module

Maps and images both represent useful data of the ground but in different forms. To match them it is necessary to extract object boundaries from both data sources. The Preparation Module involves the separate preparation of the image and the map data for matching. The selected features are extracted from map by a semi-automatic digitisation tool (using Arc\Info system) and the selection of the same areal features in corresponding image is done with a mouse by clicking on the selected features. The clicked points are the seed points of the selected image features. Having selected image features they are extracted from the image by using a region growing approach that makes use of the features in the map and the image. This module, in this way, allows the segments from the image to have a good initial match with the map before the matching process itself takes place.

3.2.2 Matching Module

The Matching Module matches the boundaries of extracted areal features of map and image to generate a dense network of match points. The matching process takes place in two ways:

- by shape based matching (Patch matching), and
- by dynamic programming (Boundary pixel matching).

The patch matching selects the best-matched polygons in image and map by integrating with the iterative region growing process (see Figure 1) and the dynamic programming finds correspondence between boundary pixels of extracted map and image polygons on the basis of a cost function. This technique requires a few control points for initialising the transformation between map and image. The centre of gravity of the map and image polygons are used for this, which are determined in the process of obtaining the parameters of polygons for patch matching. Both matching techniques were discussed before in section 2.5.

In the system improvement has been made to the patch matching technique in terms of reliability by ensuring that all the matches are correct. Each feature is extracted as a well segmented shape. There are two methods for this. First, the user does the selection of features, and second, a new approach of integration of iterative region growing with patch matching is used. Iterative region growing in each step increases a grey value threshold and merges more neighbouring pixels into regions. In this way each region (polygon) selected grows in size. A strategy developed to extract well segmented image polygons (with best shapes) is given in Figure 2.

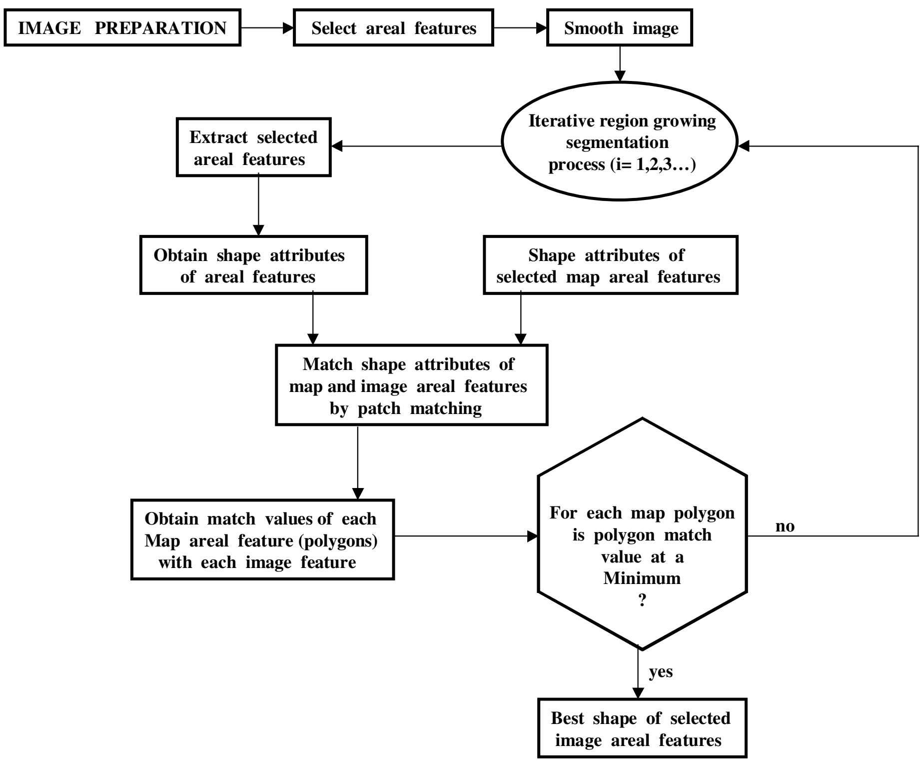

Figure 2: Algorithm for extracting selected image features with best shape.

The attributes of extracted map and image polygons are used in patch matching as mentioned before. Each selected map polygon is matched with all the extracted image polygons in the segmented images. The best matched image polygon for each map polygon is determined by a cost function. The matches with the minimum match value are corresponding map and image polygons. The method for determining the cost function is described in more detail in Dowman and Dare (1999).

The Matching Module uses the dynamic programming method on the best-matched image polygons. The method is used for determining the boundary matches of map and image polygons. This method is described in detail in Newton et al, (1994). The result of this method is proven to give good matches but errors caused by perspective distortion, shadows and occlusions are also included. The precision of map-image registration can only be obtained if the false matches are eliminated.

3.2.3 Error Elimination Module

The Error Elimination Module removes match points that include large errors. Some match points are in error as a result of perspective distortion, shadows and occlusions. This module removes erroneous match points and selects correct planimetric points using a statistical model. The model finds a set of match points (sample data), which belong to same population.

Relief objects such as buildings show perspective distortion in images. An example is given in Figure 3. In the figure the shaded area is the part of object (building) caused by perspective distortion. Matching this image with its map model will show some match points with large systematic errors, which will be the part of the shaded area. Such erroneous match points are removed using the statistical model. The method works to select a sample set of match points which are of the map model population. To remove the errors, the mean (μ) and the standard deviation (σ) of the errors are obtained and large errors removed by selecting a sample set of $\pm 2\sigma$ of the sample data. This is illustrated by Figure 4, where $\mu = 0$ and $\pm 2\sigma$ contains 95% of match points of the total. The 5% of the match points with large errors are removed by statistical model. This process is repeated until a sample set selected belongs to single population, i.e. the standard deviation of the current and the preceding process becomes the same. The selected sample set is left with random errors only and each measurement in it has the same probability of being selected as a good match point and truly belonging to the map model population.

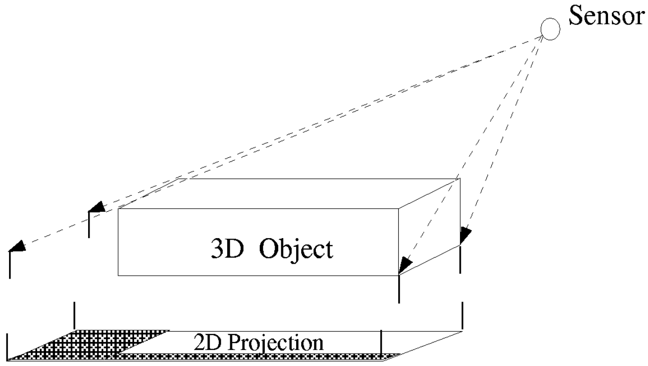

Figure 3: A model of perspective distortion.

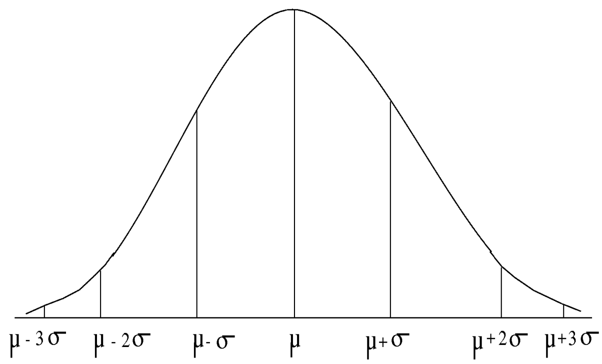

Figure 4: A statistical model for removing large errors.

3.2.4 Registration Module

The Registration Module generates transformation parameters using undistorted match points, obtained by Module 3, for a precise registration of image to map.

4 RESULTS AND DISCUSSION

The procedure explained above for the ARMIES system was tested using a SPOT panchromatic image and a corresponding topographic data set. The map data used in raster format was derived from an ATKIS 1:5,000 vector database. The map and image of a test area (Elchingen-Grosskuchen, Germany) are shown in Figure 5(top-left) and Figure 5(top-right). Five features were selected from the map and image to test the system and they were extracted from the image. See Figure 5(bottom-left) and Figure 5(bottom-right) for the extracted map and image polygons.

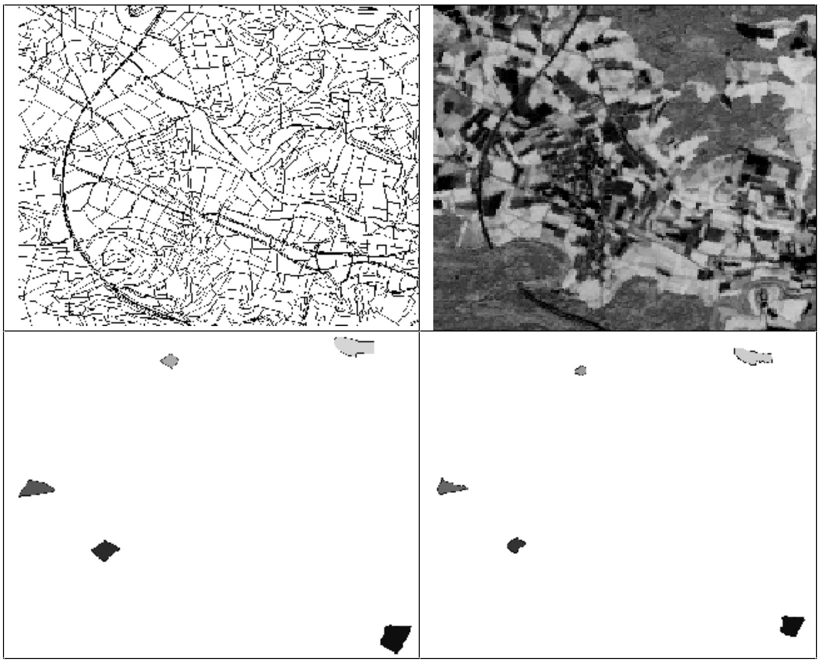

Figure 5: Map (top-left), SPOT image (top-right), map polygons (bottom-left) and image polygons (bottom-right).

The dynamic programming method used the boundary information of the extracted map and image polygons and generated 269 match points [see Figure 6 (left)]. The use of all match points showed rmse of 1.4 pixels after an affine transformation. The lower accuracy was obtained because of some false match points, which were not removed. The use of the statistical model algorithm on the match points removed the false points and selected 137 good match points (planimetric points) after 12 iterations. The statistics of each iterative step is shown in Table 1. The rmse of the last two iterations show the same value indicating that the selected points belong to the same population, i.e. the boundary pixels of the map polygons.

Table 1: Removal of erroneous match points by iterative use of statistical algorithm (units in pixels)

Iteration Number (i)	X_MIN	X_MAX	X_RMS	Y_MIN	Y_MAX	Y_RMS	T_RMS	T_RMS_{i-1} - T_RMS_i	Match points
1	-2.840	2.370	1.058	-2.950	2.310	0.918	1.400750	1.400750	269
2	-2.160	2.110	0.881	-1.740	1.890	0.662	1.102000	0.298750	234
3	-1.780	1.420	0.747	-1.240	1.310	0.531	0.916499	0.185501	207
4	-1.310	1.240	0.661	-0.940	0.980	0.381	0.762943	0.153556	178
5	-1.240	1.270	0.645	-0.760	0.800	0.255	0.693578	0.069365	159
6	-1.150	1.220	0.633	-0.510	0.360	0.171	0.655690	0.037888	148
7	-1.160	1.210	0.632	-0.310	0.340	0.165	0.653184	0.002506	146
8	-1.170	1.200	0.630	-0.310	0.340	0.161	0.650247	0.002937	144
9	-1.180	1.200	0.629	-0.290	0.350	0.150	0.646638	0.003609	139
10	-1.180	1.200	0.631	-0.280	0.300	0.148	0.648124	0.001486	138
11	-1.170	1.200	0.630	-0.280	0.270	0.146	0.646696	0.001428	137
12	-1.170	1.200	0.630	-0.280	0.270	0.146	0.646696	0.000000	137

The selected match points were used to generate the transformation parameters and register the image to the map. The registered image is shown in Figure 6 (right) with selected points plotted on it to show a quality of the registration. The rmse of 0.64 pixel accuracy was obtained using the selected points.

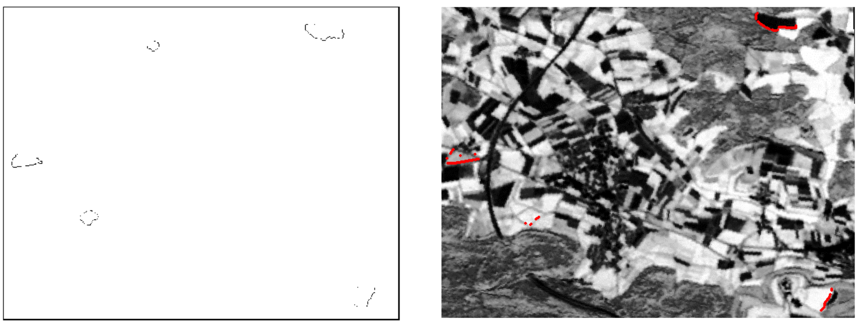

Figure 6: Matched points of map-image pixels (left) and SPOT subscene registered to the map (right).

5. CONCLUSIONS

ARCHANGEL and ARMIES provide a comprehensive suite of software to automatically register satellite images to maps at both medium and large scales. ARCHANGEL is designed as an automatic system which includes ortho rectification, but it has been shown that registration can be achieved without orthorectification if elevation distortions are small, whilst ARMIES eliminates points which might cause relief distortion.

The user of the ARMIES system does not need any expertise or training to use the system, whereas in the case of ARCHANGEL the user should be aware of all the modules included and their processes to use the system. Both the systems have shown satisfactory results and demonstrated that a complete system for registration of images to maps can be successfully constructed. Tests have shown that both systems work with limited data sets but further work is required to extend their range and performance.

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