

GEOREF: a Software for Improving the Use of Remote Sensing Images in Environmental Applications

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Abstract: Analysis of temporal sequences of satellite images is of great importance in the monitoring of environmental phenomena, where both multi-temporal and multi-spectral images are widely used. The first problem to deal with such a kind of imagery is their geo-referencing, i.e. computing a transformation to a geodetic or cartographic datum. This task is usually performed by manually measuring control points, whose ground coordinates are read on existing maps or measured by GPS. In this paper we propose a software (GEOREF) to increase the automation of this procedure, which is very heavy for the operators in the Remote Sensing field. Considering a multi-temporal sequence of satellite images, instead of geo-referencing all the images by interactive measurement of ground control points, you have to manually register only one image of the sequence to the geodetic datum. Then control points can be automatically extracted in the other images, which can be registered to the first one and thus to the ground. The paper would like to give an overview of the algorithms involved in the proposed procedure and its implementation. Furthermore some applications of GEOREF to register Landsat TM and ETM+ images are presented.

Keywords: Remote Sensing, Satellite Images, Automation, Image Registration

1. INTRODUCTION

The large number of satellites which have been launched in the last two decades allows to collect a huge amount of information about the surface of the Earth. Several kinds of multi-spectral images are available for the soil and atmosphere monitoring. In Table 1 a brief overview of some existing satellites for Remote Sensing (RS) is presented.

The advantage of the use of satellites images relies on the fact that they may be easily and continuously collected, disregarding of what happens on the ground. This allows to acquire images depicting areas involved in natural and human disasters. Optical sensors images are not the only kind of data that can be derived from RS satellites. For instance, ERS 1 and ERS 2 yield SAR images, which are used to compute Digital Terrain Models (DTMs) of the Earth surface through *interferometric* techniques [Rocca et al., 1997].

Usually data are delivered by agencies, so that everyone can buy them; in Table 1 the costs of

more widespread kinds of satellite images are shown.

As far as new satellites and sensors were introduced in the constellation around the globe, image processing techniques have been developed in order to extract more and more information from the imagery. A comprehensive review can be found in Schowengerdt [1997].

There is however one processing step being common to almost all the applications: images need to be geo-referenced, i.e. a relation between pixel coordinates and a geodetic reference system must be established. Broadly speaking, this task can be performed by computing a mathematical relation between ground and image reference, based on the measurement of a sufficient number of ground control points (GCP) in both the systems. Points on the ground may be derived from an existing map or from GPS measurements [Smith and Atkinson, 2001].

This paper will deal with the problem of measuring GCPs in temporal series of images covering the same area on the ground. This task is a preliminary

step for most geometric and radiometric analysis of the image content. Unfortunately, it is a time-expensive and boring operation, especially when dealing with small and medium scale imagery such as SPOT and LANDSAT; indeed, identifying a point on an image and its corresponding point on a map is often a difficult task. In the next paragraph a brief outlook of manual geo-referencing process is addressed.

According to these considerations, the paper propose an alternative method based on automatic image registration, which has been implemented into a scientific software called GEOREF.

2. MANUAL VS AUTOMATIC IMAGE REGISTRATION

2.1 Manual image registration procedure

The traditional way to register a RS image is based on the manual measurement of GCPs, i.e. features which can be visually recognised on the image and having “known geographic coordinates”. Reliable GCPs might be cross roads, lake or sea borders,

mountains ridges, anthropic infrastructures and the like. As mentioned above, their coordinates can be derived from existing maps or from topographic measurement (e.g. GPS). GCPs should be chosen in respect of the geometric resolution of the digital image that is to be registered. For example, for a Landsat TM (pixel size: 30x30 m) a 1:200,000 map may be used to have a synoptic view of the area and a 1:10000 map to localize GCPs and to read their coordinates.

Once all GCPs have been located either on the digital image and on the map, they are used to estimate the parameters of a geometric transformation from the image reference system to the geographic one. Usually a polynomial of degree 1, 2 or 3 is adopted.

To have a precise registration it is important to have a redundant number of GCPs (many tens per image) well distributed over the whole study area. To achieve this aim it is necessary a good skill and a lot of time, because very often it is quite difficult to recognize with a sufficient accuracy the

Satellite	Altitude [Km]	Sensor	Spectral Range [μm]	Pixel size [m]	Swath width [km]	Cost [$\text{€}/\text{km}^2$]
Landsat 7	705	ETM+	PAN 1 0.52 - 0.90 MS 1 0.45 - 0.515 2 0.525 - 0.605 3 0.63 - 0.69 4 0.75 - 0.90 5 1.55 - 1.75 6 2.09 - 2.35 TIR 1 10.40 - 12.5	PAN 15 MS 30 TIR 60	183	⁽¹⁾ Pan-Europe 0.018 ⁽¹⁾ World-wide 0.045
Spot 4	822	HRVIR	PAN 1 0.61 - 0.68 MS 1 0.50 - 0.59 2 0.61 - 0.68 3 0.79 - 0.89 4 1.58 - 1.75	PAN 10 MS 20	60	⁽²⁾ 0.35 / 0.72 ⁽³⁾ 0.94
Ikonos 2	681	PAN, MS	PAN 1 0.45 - 0.90 MS 1 0.45 - 0.53 2 0.52 - 0.61 3 0.64 - 0.72 4 0.77 - 0.88	PAN 1 MS 4	11	⁽⁴⁾ Pan-Europe 33/39 ⁽⁴⁾ World-wide 61
Eros-A1	480	PAN	PAN 1 0.5 - 0.9	PAN 1.8	12.5	11
QuickBird	450	PAN, MS	PAN 1 0.445 - 0.90 MS 1 0.45 - 0.52 2 0.52 - 0.60 3 0.63 - 0.69 4 0.76 - 0.89	PAN 0.62 MS 2.5	16.5	⁽⁵⁾ Not available (when writing)

Table 1. Characteristics and costs of the most widely used satellite data in the environmental field (PAN: panchromatic, MS: multi-spectral). (1) Prices are for map oriented full size archive images, ETM+ basic set (level 1G); (2) Prices are for archive images, Spot basic set (level 1A, 1B, 2A); (3) Prices are for new programmed acquisitions, Spot basic set (level 1A, 1B, 2A); (4) Prices are for PAN + MS map oriented images, of the same area, from the same acquisition, ordered at the same time. Prices are subject to changes.

same object on the map and on the image. In order to give an idea of the time for georeferencing an image to a map, for a Landsat TM image covering an area of 9000 km² it may take about 4-5 days of

one-man work, according to a hundred points to select and measure.

When dealing with a multi-temporal sequence of images, only the first of them must be georeferenced to the ground, then the others may be registered to that. Manual *image-to-image* registration is easier than *image-to-map* registration, although this requires several hours of man work.

2.2 Automatic Image Registration Procedure

Automatic image registration means to find a set of GCPs in an image by means of an automatic procedure. GCPs can be derived from a map, from topographic measurements or from another image which has been previously geo-referenced. From an operational point of view, the problem is always to find a set of corresponding features between two images. This is evident when using a map or an image, but it's true even in case you try to recognize GPS points.

Now, several techniques for finding homologous points between a pair of images are well known from *image processing*: it's the problem of *digital image correlation*. On the contrary, more difficult it's to look for correspondences between a map (both in raster or vector format) and an image. In the case of *image-to-image* registration algorithms are based on looking for a geometric similarity between two elements (*feature-based matching*) or directly comparing pixel values (*area-based matching*). In the case of *image-to-map* registration, similarity is to be found at a higher level, i.e. based on abstract models or on relations between diverse features (*relational matching*). This last problem is more complex to solve; yet solutions and algorithms have been proposed, they are always a small field of application.

Focusing only on algorithms for *image-to-image* registration, main problems to solve for are two:

- Images may differ for scale, orientation, lighting, and the geometry of the image itself may be different in case of images acquired by diverse kinds of sensors. Then, a procedure to compute image registration should first provide an approximation for the registration parameters. This task can be performed using *feature-based* or *relational matching* techniques; another approach is to use *area-based* algorithms through a *multi-resolution* procedure.
- A sufficient set of control points has to be accurately measured on the pair of images. For this task *area-based* algorithms are more suitable, in particular if they are able to keep into account geometric and radiometric

differences between images (e.g. *least squares matching*).

3. A SOFTWARE FOR AUTOMATIC REGISTRATION OF RS IMAGES

The automatic image registration of multi-temporal sequences of RS images can be performed by using the software GEOREF. Considering a set of images covering the same area on the ground, GEOREF allows to mutually register them *image-to-image*. If at least one of the images of the sequence has been already georeferenced to the ground, then all the others are consequently registered.

GEOREF has been thought to cope with the georeferencing of large volume of images, e.g. in the study of the evolution of soil-covering through the time. The use of GEOREF enables to limit the amount of manual measurements only to the points needed for the registration of one image of the sequence. The fact that nowadays mosaic of georeferenced satellite images covering a whole country become to be available increases the possibilities offered by GEOREF; for example, the mosaic of Landsat TM covering the U.S.A. has been recently completed. In such a case, a registered image of a given area may be purchased, and other images covering the same area can be then georeferenced without the manual measurement of other points.

Except the manual registration of one reference image, a limited pre-processing work is required before running GEOREF. Usually images are multi-spectral, so a single channel image at 8 bit/pixel must be prepared by selecting a band or a combination of bands. If more than two images are to be registered, images of the sequence are processed pair-wise; the order of the sequence must be selected by the user. Furthermore, an initial approximation for the registration parameters of each image pair must be set up; a 2D conformal transformation is usually enough, only requiring the manual measurement of at least two homologous points.

Once the data-set is ready, GEOREF can be executed on each pair of images, yielding two final products:

- The transformation parameters to register the second image to the first one (a 1-2 degree polynomial can be selected);
- The image coordinates of control points extracted in both images.

This output data can be used in a program for RS image processing to apply the computed transformation and to warp the second image.

In case of dealing with an image sequence, the process is repeated by registering a third image to the georeferenced one and so on.

In the next two paragraphs, first a short outlook on the strategy and algorithms implemented in GEOREF will be addressed, and finally a description of the software presented.

3.1 The strategy for automatic image registration

The strategy adopted for *image-to-image* registration is based on *multi-resolution*, i.e. for each original image is derived a sequence of images having half the resolution of the previous one (*image pyramid*). Usually a 3-4 level *image pyramid* is used (see Figure 1). The extraction of control points starts on the pair of images at the lowest resolution; thank to the points extracted at this level, a first set of transformation parameters is computed. These parameters are then used to help the registration of the pair at the next level, and so on as far as the original images are involved and registered. The use of *multi-resolution* reduces the dependency of the initial approximate values of the parameters.

The extraction of control points is carried out at each *image pyramid* level in two steps. First of all, in every image a set of *interest points* is extracted by *Förstner operator*. Interest points are usually located close to well contrasted features. Starting from image 1, for each *interest point* (“master”) the possible position of the homologous point on the image 2 is predicted, thank to the knowledge of approximate registration parameters. Then all the *interest points* falling into a square window around the predicted position on image 2 become “slaves” and are considered as candidate to be the true homologous.

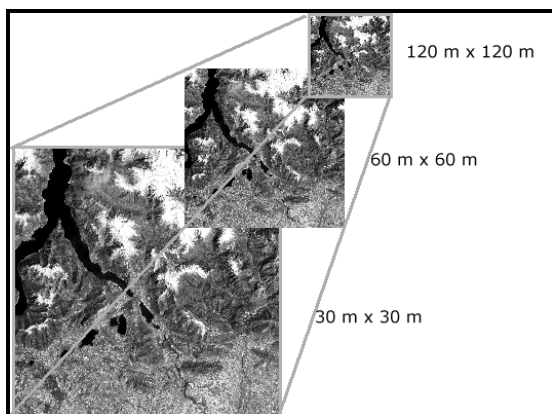


Figure 1. Example of multi-resolution image pyramid

At this point the core algorithm of the registration procedure is used: *least squares matching* [see Baltasvias, 1991 for a review on this subject]. Two square windows, one around the master point on the image 1 and the other around the slave point are extracted. By applying a *least squares* estimation, a set of geometric (usually an affine transformation) and radiometric parameters are computed for each point in the way to minimize the differences between “master” and “slave” window. The *correlation coefficient* between the “master” and the warped “slave” is then computed, either to access the quality of matching and to selected among all the candidates.

Unfortunately, matching algorithms allow to extracted several corresponding point, but they are more error prone than human operators. To cope with the high number of outliers which could bias the parameters’ estimation, a robust estimator is used. The algorithm adopted is *least median squares* [Rousseeuw and Leroy, 1987], which is able to deal effectively also with a percentage of errors in the data-set of 30-40%.

A larger description of the algorithms and related references has been already reported in Carrion et al. [2001].

3.2 Implementation of GEOREF

The procedure reported in the previous paragraph has been implemented into the software GEOREF. The code has been written in C and FORTRAN 77 and runs in UNIX environment. The current release is still a scientific version and the data input is done by command files. A new release with an improved user-interface and a PC version are work-in-progress.

In the diagram reported in Figure 2 the workflow of GEOREF is depicted. The software starts by preparing the image pyramids and by extracting interest points from the images. Then the procedure to find and to measure control points is executed, beginning at the lowest level of resolution of the image pyramids.

The software asks the user to set up a set of control parameters for the algorithm adopted (e.g. to set up the threshold of the *correlation coefficient* to decide whether two points are homologous or not). Usually there is a set of standard values for these parameters, which has been proved to be valid in a large number of applications. However, GEOREF

may adjust some control parameters by itself if satisfying results have not been reached; for example, if the *interest operator* has not yielded a sufficient number of points, it is applied again by modifying its control parameters.

4. APPLICATION OF GEOREF TO REGISTER LANDSAT IMAGES

The tests of the software GEOREF have been carried out to register Landsat images. This kind of images are of great importance for the study of the soil usage in the time. They are available for more than 20 years, with a frequency of two images per month. Furthermore, as said above, diverse Countries have already a coverage of the most part of their lands made up of georeferenced Landsat images.

Two tests are presented here. The first one [see Carrion et al., 2001 for more details] has involved a small set of images covering the area of Como Lake (Italy); images have been taken in different seasons of the year in 1984, 1990 and 1999. The geometry of the images is quite similar, while significant differences are present in radiometry, in particular due to different degrees of snow coverage.

These images have been mutually registered by GEOREF. In order to access the real accuracy of the registration, some other control points have been measured on the same images. By applying to these points the transformation computed by GEOREF an evaluation of the accuracy of the registration itself has been carried out. This test has given an accuracy of less than 1 pixel for the images of better radiometric quality, and about 2-3 pixel for the others. Furthermore, an important finding is the fact that the algorithm is practically independent from the snow coverage.

The second test has been carried out by considering two images covering an area in Lombardia (Italy), near the Garda Lake. Peculiarity of this pair of images is a not negligible rotation between them, due to the warping procedure applied on the first one. Images have been acquired in 1985 and 1990.

The 1990 image has been georeferenced to the UTM reference system, manually measuring on it 40 GCPs. Ground coordinates of these points have been derived from a topographic map of the area. Their mensuration have taken 4 days of human work to an expert operator.

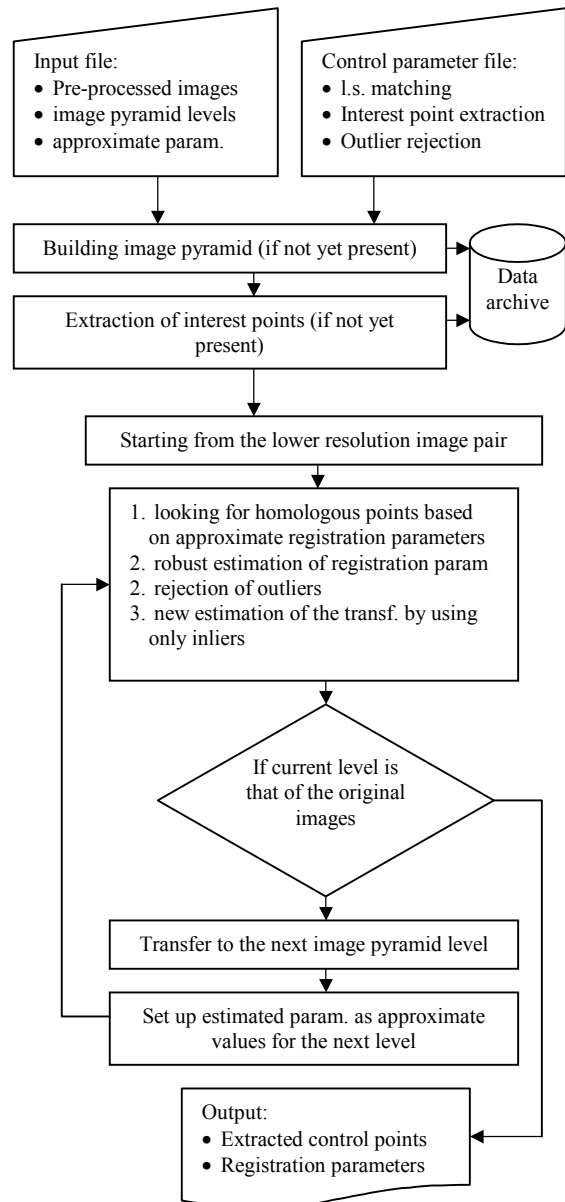


Figure 2. Workflow of the program GEOREF.

The 1985 image has been registered to 1990 image by applying GEOREF (see Figure 3). The number of control points extracted on the original images by the software was 160. Thank to these points, a 1 grade polynomial has been estimated and the slave image has been warped to the master image already georeferenced to UTM. In order to access the results, a vector layer derived from Corine Land Cover map has been superimposed to the 1985 warped image. Results are satisfying, because the warped Landsat image presents small deformations.

Moreover, this test has shown how the *multi-resolution* approach allows to compensate for poor initial values for the registration parameters.

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

The software GEOREF allows the automatic registration of satellite images covering the same area on the ground. Its use permits to avoid the most heavy step in RS image processing, that is the traditional georeferencing procedure based on manual measurement of control points.

Some tests have shown the real capabilities of the software, which have been tested considering Landsat images. Other experimental applications should be made by trying to register other kinds of satellite images.

Currently the software GEOREF is available freely upon request at <http://it.geocities.com/georef2001>. Its use is limited to academic and not commercial applications, otherwise, agreement with the authors must be taken.

5. ACKNOWLEDGEMENTS

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Figure 3. The automatically georeferenced Landsat image with superimpose a vector layer of Corine Land Cover Project