GEORIS : A TOOL TO OVERLAY PRECISELY DIGITAL IMAGERY

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ABSTRACT

The main requirement for satellite and airborne imagery exploitation is to make conform (overlay) these images (optical, radar, infrared, etc) to a working geographic model that can be either a map or another reference image. The GEORIS tool method is to accurately overlay an image with any other image by using only the image contents. The image analyst community dealing with operational crisis management and fast decision making has required this important operational constraint. Indeed, in operational near-real-time context, different images and maps shall be often combined without knowledge of the sensor characteristics. To solve the current polynomial-registration-method drawbacks, a new state-of-the-art technique has been designed and developed using a registration model which integrates ground control and tie points, as well as recognised linear features (roads, power lines, railways, pipe and water networks, bridges, buildings, shorelines, etc). Firstly, linear features are used to calculate the polynomial model accuracy and estimate its residual quality. Secondly, the linear features are used to define a graph model including thousands of control points. Then, a numerical process to match the graphs is used to optimally estimate the best registration model. For mountainous areas or inaccurate maps, a polynomial model cannot be applied, even if it has a high order. The developed GEORIS method proposes a multiple local fitting model approach. Such a technique has the advantage of taking into account local relief and increases significantly the matching precision. To improve further the relative pixel positioning accuracy, the last GEORIS version is able to use a digital elevation model when available.

1. INTRODUCTION

To exploit a set of digital spaceborne and airborne images and maps either for image analyses and data fusion or more sophisticated data post-processing like with GIS facilities, it is necessary to register all of them in a common geographic co-ordinate system.

From an operational point of view, the obtained registration accuracy conditions the reliability of the derived information, extracted from the data. Therefore, this step is important and requires careful methodology to perform the multiple source data registration (spatial and spectral) and its quality control. The quality control of the registration accuracy provides to the user confidence that the set of images and maps can be correctly matched to extract reliable information.

Classically, geometric registration is based on two different approaches. The first approach, is based on the use of sensor geometric models, including observation features and orbital parameters (Crawford et al., 1996, de Sève et al., 1995, El-Manadili and Novak, 1996). In this case, requirements are the availability of complementary information such as satellite ephemeris, correct sensor models and sometimes digital elevation models which are usually not supplied with the set of images (Palà and Pons, 1995). In addition, in a real-time operation context, such as for natural disasters (floods, earthquakes, fires, etc), these required additional data are most of the time not immediately available or even not existing.

The second, more empirical, approach relies on matching ground control points (Jensen, 1996). The drawback is the difficulty to automate the process of registration which is done under the control of an operator, except in some cases where a database of reference GCPs has been pre-computed (Holm et al., 1997).

In this study, the second approach has been investigated. To satisfy operational needs, the provided images shall be exploited as they are. In other terms, only spaceborne and airborne image contents are used and contribute with other data sources to characterise the risk and its temporal development. Therefore, to support such operational requirements, a procedure and methodology shall be designed to integrate images, maps and site reports as they are and produce an accurate overlay of all this data.

In this context, a system called GEORIS has been designed and developed by the ACRI company under a WEUSC contract (Western European Union Satellite Centre, Madrid).

The aim of this article is to provide an overview of the GEORIS system, and especially of the model used.

2. GEORIS MODEL

The core of the software computes mathematical models to geometrically register an image with a second image or map which is used as the reference (the reference image is usually a geo-coded image called master).

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The main characteristics of the GEORIS geometric correction model are:

- Global correction (using a classical polynomial function)
- Local correction
- Capability to use linear features

2.1. Global correction

A first global model is calculated using an empirical approach based on tie points measured by the operator in the set of images. The tie points are used to determine the coefficients of a polynomial transformation (least squares minimisation). This model allows performing the main geometric correction.

A polynomial function of order one handles similarity and affine transformations (rotation, scale, translation). A higher order polynomial permits modelling of more complex distortions, e.g. due to attitude variations. However, the use of order higher than two is dangerous; if the number of tie points is limited and/or their spatial distribution poor, it usually leads to wrong corrections.

The quality of the model is usually evaluated through the use of the residuals at each tie point (error between the location of the tie point and the location given by the model). When a tie point has a larger residual than the other ones, it is usually re-visited by the operator to check whether it is due to a pointing error. However, in most of the cases, this error does not come from the tie point measurement but from local deformation (for instance, due to the relief). This type of problem can usually not be solved using this classical approach. A larger set of tie points will minimise the problem locally but will generally introduce a larger error around this area. To limit this risk, especially because the operator does not know the mathematical approach used, control tie points are required. Then, residuals are computed but the control tie points are not used in the least squares estimation.

In the GEORIS system, there are in fact four categories of tie points available:

- Control tie point: not considered in the minimisation process
- Normal tie point: this is the usual case
- Questionable tie point: the user is not confident in the location of the tie point (because of difficulties to point it in the image with a good accuracy)
- Super tie point: when the user is very confident in the location of the tie point

The last three categories of tie points are introduced in the minimisation process using different weights. This approach has a small overhead for the user but permits during this step the analysis of residual errors and leads to higher accuracy.

At this step, a pixel of co-ordinates (X_i,Y_i) is transformed in the coordinates (x_i',y_i') in the other image using a polynomial function f.

$$(X_i,Y_i) \xrightarrow{f} (x_i',y_i')$$

For each tie point, the coordinates (xi, yi) in the other image are known. This permits to compute residuals defined by Eq. 1:

$$dx_I = x_i - x_i' \qquad (1)$$
$$dy_I = y_i - y_i'$$

2.2. Local correction

A specific characteristic of GEORIS is the use of a local model. This model guarantees that each of the selected tie point, measured by the operator, will be perfectly fitted by the model (no positioning errors on selected tie points). This local correction is applied taking into account the tie point neighbourhood area, whose size depends of the surrounding tie point context (i.e., road crossing, bridge over a river, shoreline, etc.). Obviously, this local model permits to correct for local deformation errors such as introduced by the terrain relief. If a digital elevation model is also available, the local correction can be automatically linked to a 3-D function (horizontal position and altitude). In this case, the local model and correction are achieved taking into account the third dimension.

When no DEM is available, the pixel coordinates (X_i,Y_i) are transformed to (x_i'',y_i'') in the other image using successively a polynomial f plus a function l_i (called local correction):

$$X_i,Y_i \xrightarrow{f} (x_i',y_i') \xrightarrow{li} (x_i'',y_i'')$$

The function l_i depends on the location of pixel X_i,Y_i.

For a tie point X_i,Y_I, it is a translation corresponding to the residuals (dx_i,dy_i), see Eq. 2.

$$x_i'' = x_i' + dx_i \qquad (2)$$
$$y_i'' = y_i' + dy_i$$

For another point (X_i,Y_i) of the image and its transformed coordinates (x_i',y_i'), the translation dx_i,dy_i is defined by:

$$dx_i = \sum_k p_k \sum dx_k / p_k \qquad (3)$$
$$dy_i = \sum_k p_k \sum dy_k / p_k$$

where:

k: number of tie points
p_k: distance between (x_i',y_i') and the tie point (x_k,y_k)
dx_k: residual value (along x axis) of the tie point k
dy_k: residual value (along y axis) of the tie point k

This means, that the translation depends on existing surrounding tie points, each with a weight depending on its distance from the currently processed tie point.

This approach has been shown to be interesting in many cases. Table 1 shows the results of two typical cases where this approach is especially useful. The first one corresponds to results obtained at a mountainous area (using SPOT images

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with an incidence angle of 27 degrees). The second corresponds to the case of a reference map (Michelin Map) and a historic map (Cassini map of 1756). The local approach guaranties a residual value of 0 for the tie points used by the process. Table 1 shows the errors (mean, minimum and maximum values) estimated using control tie points. A considerable improvement through the use of the local correction is noted due to the fact that the local deformation is usually smooth.

	Polynomial approach	Polynomial + local approach
Mountainous area (34 control tie points)	19.5 , 0.5 , 46.6	9.1 , 0.7 , 28.3
Cassini map (22 control tie points)	9.1 , 4.8 , 19.9	6.2 , 1.1 , 13.1

Table 1. Coregistration errors (mean, minimum, maximum) for two methods (in pixels).

When a DEM is available (only required for the master image), we assume that the correction to be applied is a function of the height (see Eq. 4).

$$dx_i = a\, z_i + b \qquad (4)$$
$$dy_i = a'\, z_i + b'$$

The coefficients in Eq. 4 are estimated using the set of tie points (weighted in the same way as previously).

When a DEM is available, this approach can provide more accurate results. For instance, in the case of the mountainous area, the error decreases from 9.1 to 1.3 pixels (see Table 2).

	Polynomial + local approach with DEM
Mountainous area (34 control tie points)	1.3 , 0.2 , 2.6

Table 2. Coregistration errors (mean, minimum, maximum) when using local corractions and a DEM (in pixels).

2.3. Use of Linear Features

Another important characteristic of the GEORIS software is the capability to use, in addition to the tie points, selected linear features (road, railway, power line, shoreline, pipe, etc.) to compute the global and local models. These features are directly pointed by the operator (depending on the spatial resolution and the positioning accuracy to be reached, the features should be carefully pointed at, e.g. either the road strip or one of the edges of the road or the centerline of the road). When pointing a linear feature (i.e. road strip), it is not required that the beginning and the end of the linear feature have the same location in both images to be registered; only a common segment is needed. The linear features can be used either to calculate the registration error (from the results of matching of the linear features after the global and local models are applied to the image to be registered) or to compute the models themselves by using thousand of tie points which are automatically generated along the selected linear features.

The registration error is estimated using a statistical approach. For each point of a considered feature, the model is applied and we search the nearest pixel of the corresponding feature in the other image. The distance obtained is used as an estimate of the matching accuracy. To limit matching errors, the matched pixels which involve the end points of the feature are ignored.

This very simple approach permits to benefit in many cases, e.g., if only one straight line feature is available, it could be used by the system. This method is especially interesting to provide an estimation of the accuracy of the model without needing a large set of control tie points and with a better spatial distribution. Table 3 shows results (mean error) obtained for the previous examples.

	Polynomial approach	Polynomial + local approach	Polynomial + local approach with DEM
Mountainous area (ca. 5500 points)	8.3	3.8	1.0
Cassini map (ca. 2800 points)	3.7	3.4	-

Table 3. Mean coregistration error (in pixels) using feature points as control tie points.

In this case, linear features are used by the system as control tie points. Another mode that can be requested from the system is to use linear features as tie lines in order to improve the model. This function is implemented by an iterative process which automatically adds new tie points along a feature. This approach permits the user to visualise and control the tie points added by the system.

3. GEORIS TOOL

To meet the user and performance requirements specified, an exploitation procedure has been implemented to guide the operator step by step: select the zones of interest; catch the common features; calculate the registration model parameters; assess the positioning accuracy; apply the registration model; archive and export the registered images together with the registration models and the feature attributes.

On-line easy-to-use tools are available to support the operator to draw precisely the features with scrollable zoom, improve the image contrast, adjust the position of ground control points and assess the relative positioning accuracy of any pixel in the image to be registered.

As GEORIS is dedicated to prepare a set of images for photo-interpretation tasks, an export facility has been developed to allow either projection of the raster and vector data in a selected

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geographic coordinate system or export of the original images with the associated registration model and the matrix of the relative positioning errors.

For interpretation and analysis tasks, the registration model allows to navigate through the set of the original images on the screen. This fast on-line computation has the advantage of preserving the original image signatures for photo interpretation purposes and allowing application of sophisticated multispectral processing to corresponding pixels.

The software functionality is completed with a facility to update a map with standard symbols and annotations or by using previous interpretation results from current registered spaceborne and airborne images. It is particularly interesting for management of temporal changes of sites (e.g., with natural disasters).

4. CONCLUSIONS

In 1998, extensive benchmark tests have been performed with optical and microwave spaceborne images (SPOT, IRS-1C, LANDSAT, RADARSAT) and maps of different scales and cartographic projections. Very good registration accuracy has been demonstrated even with very large images (i.e., 20,000 x 20,000 pixels) and in mountainous areas.

In the first quarter of 1999, the software was installed in the operational information system of the Satellite Centre (Madrid) of the Western European Union, and is routinely used to register images and maps for photo-interpretation and image analysis tasks.

At ACRI, the software is also operationally used to match numerical simulation results for air and water pollution with aerial and satellite images and local maps.

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