AUTOMATED IMAGE-TO-IMAGE REGISTRATION , A WAY TO MULTI-TEMPORAL ANALYSIS OF REMOTELY SENSED DATA

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ABSTRACT. The digital overlaying of images is the only way to the multidimensional analysis of data, but a qualitative assessment. In Remote Sensing, the multitemporal analysis is useful for studying the evolution of many physical phenomena, and now the merging of Visible, near or thermal Infra-Red and Microwave data, opens a new field of investigations.
A set of several methods - some of them are now classic ones - is shown in this chapter, and we try to point out the troubles met in automated registration : what happens to the physical content of the remotely sensed information with respect to the processing applied?

KEY WORDS. Correlation, Edge Detection, Multitemporal Analysis, Rectification, Registration, Overlaying, Remote Sensing.

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1. THE IMAGE OVERLAYING AND THE "MULTI" CONCEPT IN REMOTE SENSING.

The image-to-image registration is not really a new problem, but it is concerned by automatical processing for only about ten years.
Indeed, since the launch of the first Earth Ressources satellite, the ability of getting multiple data has notably increased in the Remote Sensing domain.
It is what is called the "Multi" Concept by COLWELL in (1): multispectral,multitemporal,multistage,multistation,multisensor.
Let us write the Multi Concept as a function :

$$(x,y) \in \text{geographical domain} \longrightarrow f(x,y) \in \mathbb{R}^n$$

Most of the work published on Registration and Overlaying has been done on LANDSAT-MSS images:(2) to(8). The Table 1.1 summarizes the overlaying difficulties with respect to the Multi Concept, and the Table 1.2 describes the registration and the rectification in the overlaying processing.

2. THE REGISTRATION AND ITS PROCESSING.

In the registration processing -i.e. the determination of couples of homologous pixels (or "control points", or "amers") - several questions need answer :
- what to register for getting a location of pixel?
- how to register?
- can we trust the registration result?

WHAT ? the processing cannot be punctual but local. Two ways can be followed, which handle:
- the radiometric levels on a neighborhood (information of continuity)
- the result of some local edge operator (information of discontinuity): table 2.1.

HOW ? several similarity functions can be used for computing a registration index: table 2.2.

TRUST? two ways for selecting trusty indexes:
- a-priori selecting: a criterion discriminates the control points which are the ablest for succeeding in the registration (t. 2.3(a))
- a-posteriori selecting: several criteria discriminate reliable indexes (t. 2.3(b))

Table 1.1. The Multi-Concept and the Image Overlaying.

MULTI-	AMOUNT OF DATA (examples)	OVERLAYING ABILITIES
SPECTRAL	LANDSAT-MSS: 4 bands METEOSAT: 3 bands SPOT: 3 bands (20meters) 1 band (10meters)	Easy (in general) Offset or slight rotation due to the instrument
TEMPORAL (same sensor)	LANDSAT: 1 scene/18 days METEOSAT: 48 . / 1 . SPOT: 1 . /26 . (vertical mode) 1 . / 5 . (non vertical)	More or less difficult (more for airborne data than for satellite data) Model of the movement to be estimated
SENSOR	LANDSAT(80m.) on Radar VIGIE(15m.) or on DAEDALUS (3m.)	Various and complex modeling Intermediate cartography is necessary

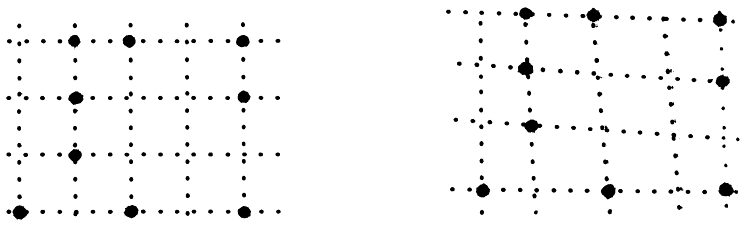
Table 1.2. The REGISTRATION and the RECTIFICATION.

Image 1= REFERENCE Image 2= CANDIDATE

(x,y) o o (u,v)

for each fixed pixel ... finding the location of its homologous

... this operation n times again ...



and recording each couple of homologous pixels.

REGISTRATION

Then using all the couples for fitting a model of the relative geometric deformation between the REFERENCE and the CANDIDATE.
Then applying this model and some interpolation processing for computing the radiometric values for the CANDIDATE at every node of the grid defined by the geometry of the REFERENCE.
(see GOLDBERG's chapter)

RECTIFICATION

Table 2.1. Example of discontinuity detection.

Original image ↓
Improve the local homogeneity by using a non-linear median smoothing: on each 3 by 3 neighborhood, let us compare the central pixel with the others. If it has the highest or the lowest value, replace it by the median value. ↓
Detect the edge by using a local derivating like: $d_{i,j} = 1/4\ (\lvert x_{i-1,j-1} - x_{i+1,j+1}\rvert + \lvert x_{i,j-1} - x_{i,j+1}\rvert + \lvert x_{i-1,j} - x_{i+1,j}\rvert + \lvert x_{i-1,j+1} - x_{i+1,j-1}\rvert)$ ↓
Get a binary information by thresholding the histogram of the $d_{i,j}$'s at 20% of the highest values, for example.

Table 2.2. Registration index (or Similarity)

Correlation coefficient	$\rho_{lk} = \dfrac{[N^2 \sum_{i=1}^{N} \sum_{j=1}^{N} x_{ij} y_{i+l,j+k} - (\sum_{i=1}^{N} \sum_{j=1}^{N} x_{ij})(\sum_{i=1}^{N} \sum_{j=1}^{N} y_{i+l,j+k})]}{\sqrt{[N^2 \sum_{i=1}^{N} \sum_{j=1}^{N} x_{ij}^2 - (\sum_{i=1}^{N} \sum_{j=1}^{N} x_{ij})^2]\ [N^2 \sum_{i=1}^{N} \sum_{j=1}^{N} y_{i+l,j+k} - (\sum_{i=1}^{N} \sum_{j=1}^{N} y_{i+l,j+k})^2}}$
Covariance function	$r_{lk} = \sum_{i=1}^{N} \sum_{j=1}^{N} x_{ij}\, y_{i+l,j+k}$
Absolute difference function	$a_{lk} = \sum_{i=1}^{N} \sum_{j=1}^{N} \lvert x_{ij} - y_{i+l,j+k}\rvert$
Graph correlation coefficient (binary values)	$g_{lk} = \dfrac{\sum_{i=1}^{N} \sum_{j=1}^{N} x_{ij}\, y_{i+l,j+k}}{\sum_{i=1}^{N} \sum_{j=1}^{N} x_{ij}}$

Table 2.3(a) A-priori selecting.

-Among N windows around a fixed reference window, let us choose the one which maximizes the number of "chained edge pixels", for a given edge detector and for a given chain length (9).

-If the type of edges to be detected is well known, let us unite the information of discontinuity and the radiometric information: an example with METEOSAT images is given in (10).

Table 2.3(b) A-posteriori validation.

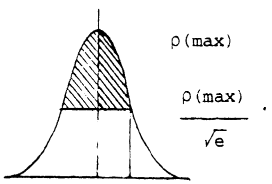
The Registration Index always has a maximum value on the surface on which it is computed. The question is : is this maximum a peak of correlation which indicates the good position of the homologous pixel on the CW ?
The answer will be positive if the three following criteria are positive :

let $\rho(\max)$ be the maximum of the set $\{\rho_{1,k}\}$

1. EXISTENCE $\rho(\max) > \bar{\rho} + 3\,\sigma(\rho)$

2. UNIQUENESS the i highest values below the max. :
$\rho(\max-1), \rho(\max-2), \ldots \rho(\max-i)$
belong to some neighborhood of $\rho(\max)$

3. SHARPNESS let N be the cardinal of the subset
$\{ (1,k) \; ; \; \rho(\max)/\sqrt{e} < \rho_{1,k} < \rho(\max) \}$
and N_{tot} the cardinal of the complete set $\{(1,k)\}$
then : $p = N_{tot}/N < p_{max}$



for estimating p_{max} let us see the normal Gaussian distribution : the hatched part contains 19.8 % of the total surface.

Several combinations of these processing have been tried by several authors, comparative studies have been done (11)(12).

The Flow-Chart of the table 2.4.(below) shows the processing sequence used in (12) which works with discontinuity detection, graph-correlation (or FFT-correlation) and a-posteriori validation.

Let us notice that the similarity -or registration- index can measure only the fitness of a registration by local translation. If the deformation is too strong, it cannot be locally approximated by a translation and then it is necessary first to rectify the Reference window with a model (coarse or updated): this part is written in *script*.

An example of the Previous Rectification is shown by the table 2.5.

Table 2.4. Flow-Chart of the Registration Processing.

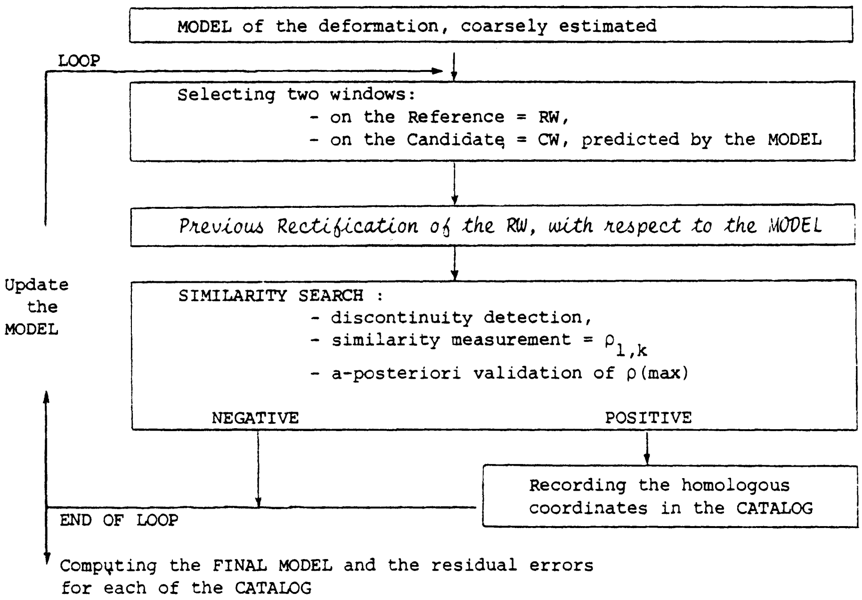
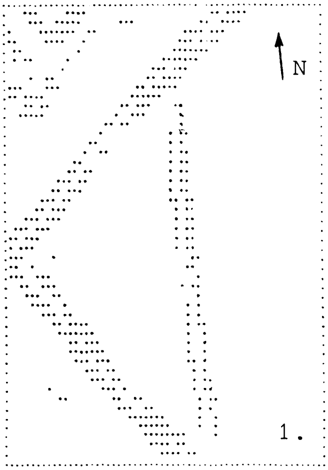
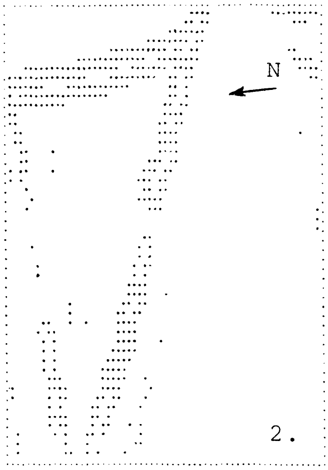


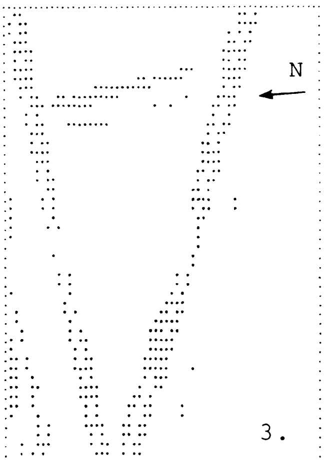
Table 2.5. Example of the application of the previous rectification

The images are from an airborne DAEDALUS, taken from two perpendicular flights (high resolution = 3 m. along track, wide field of view = 78°)

Part of the Reference, of the Candidate







1. Edges detected on the Reference window.

2. Edges detected on the Candidate window.

3. Edges detected on the RW after the previous rectification.

3. HEALTH OR PATHOLOGY OF SOME EXAMPLES WITH LANDSAT

Let us watch the behaviour of the former algorithm, with respect to several physical parameters, by investigating some regions in FRANCE (see list below), which are rather different from most of the agricultural regions in the USA.

Regions	Characteristics
BEAUCE	Agricultural area, surface of fields: from several hectares to several tens of hectares
MARAIS POITEVIN	Coastal area, presence of water/land discontinuity
GIRONDE	Heterogeneous agricultural area (vineyards) Wide river (Dordogne)

3.1. Relationship between the Resolution (R) of the sensor and the Surface (S) of the topological elements. The optimal ratio for getting discontinuities which fit the similarity search, should verify:

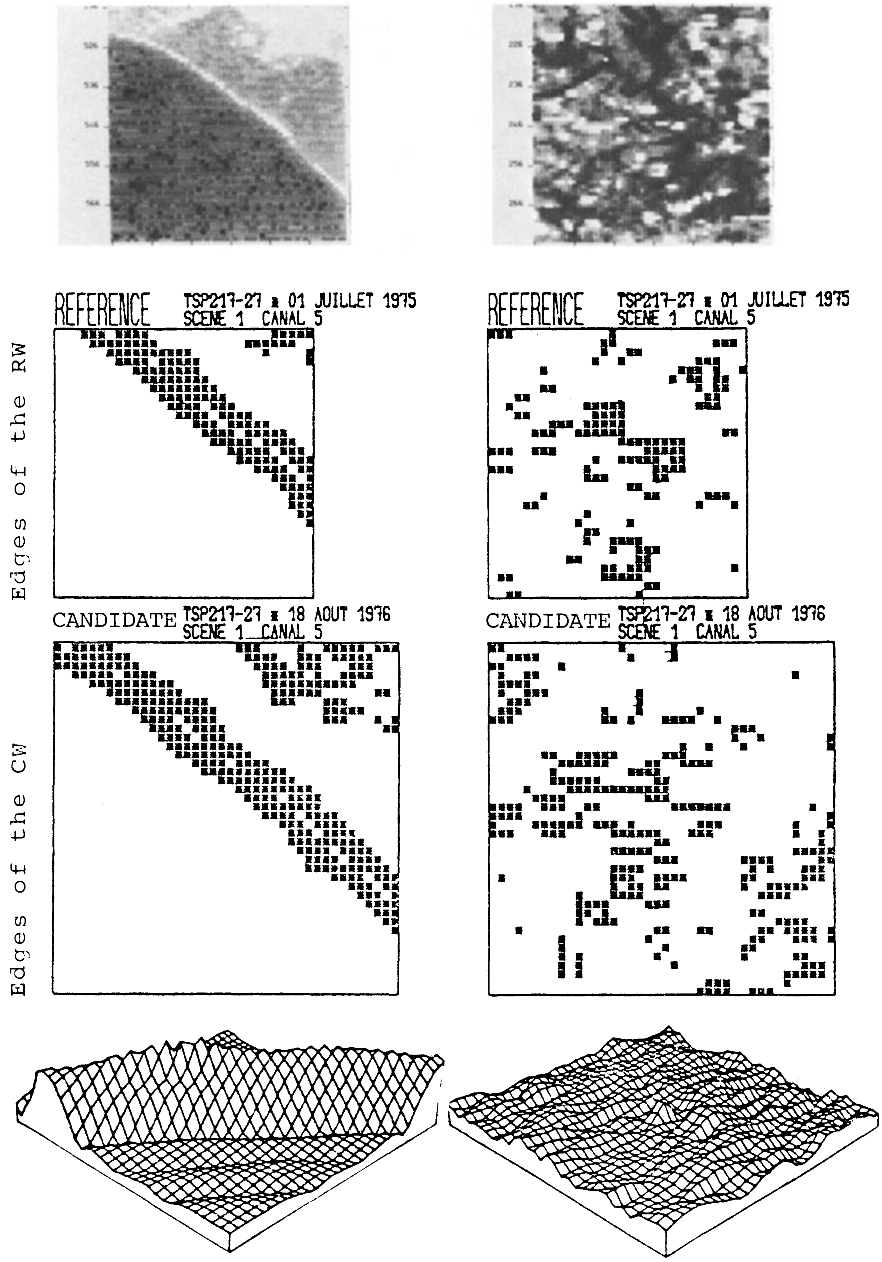
$$30 < S / R^2 < 300$$

for an algorithm using RW of 32 by 32 pixels and an edge operator of 3 by 3 pixels.
The figures 3.1(a) and (b) show examples where S is too large or too small for the LANDSAT resolution = 80 m.

The Figure 3.1(c) shows a pathologic case, where the main element of the countryside (the river) has a size which fits the resolution quite well along one direction and badly along the perpendicular one. The final result is a success because of some other small structures being in the same area.
The three main ridges which appear on the correlation surface mean we can register the riverbanks well, or the right one over the left one, and vice versa.

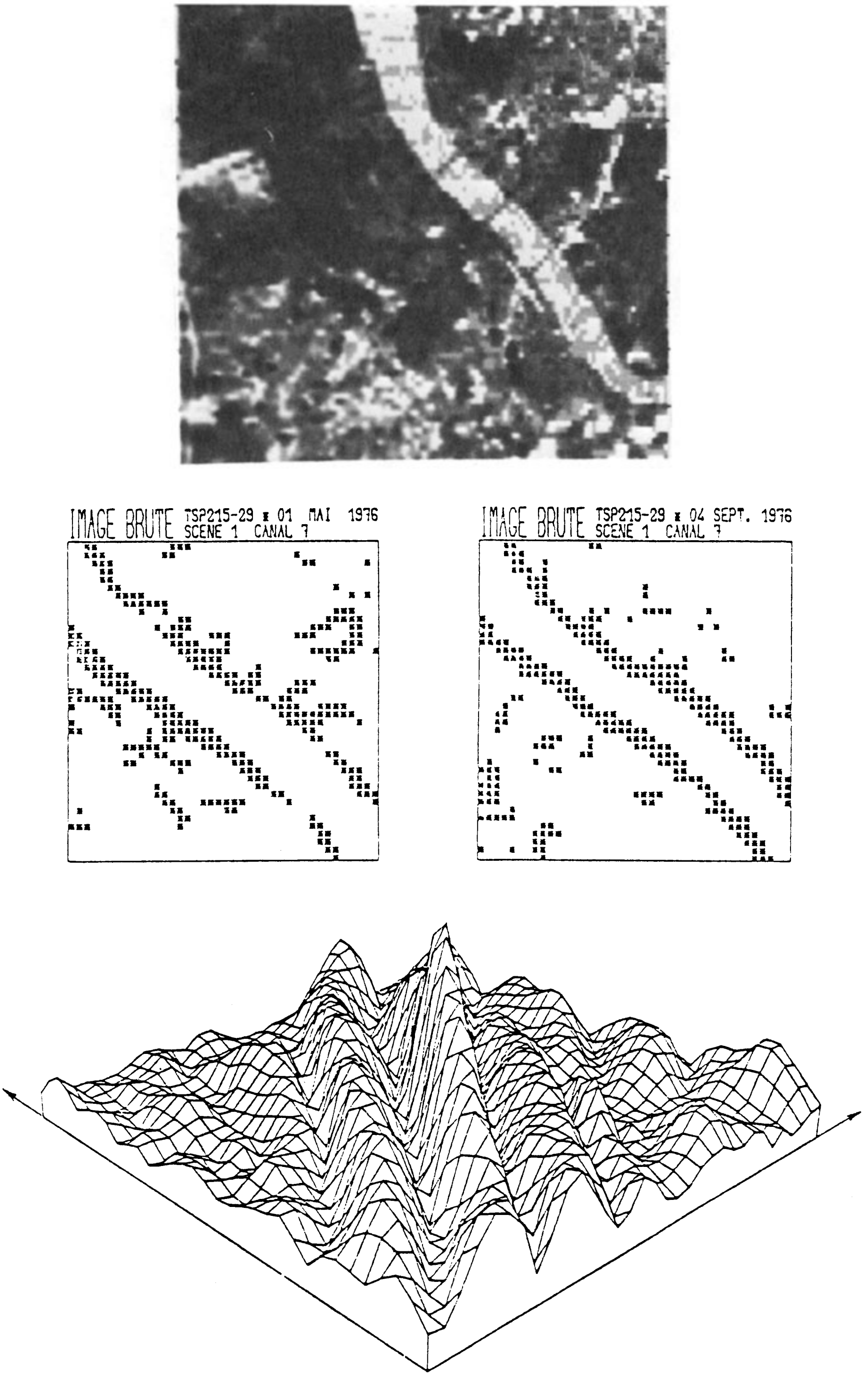
Figures 3.1. Influence of the ratio S/R^2

(a) the "Côte Vendéenne" S too large (b) the "Marais Poitevin" S too small



Two unsuccessful correlation surfaces.

Figure 3.1(c) The Dordogne river



3.2. Relationship between the Date, the Spectral Band, and the Type of countryside.

Over an agricultural area like the BEAUCE, we can observe the following results (over 24 tests) :

BAND	March/ April	April/ April	April/ July	July/ July	July/ August	% of
5	0	75	92	83	96	TP
	0	21	8	17	4	FN
	75	4	0	0	0	TN
	25	0	0	0	0	FP
7	33	96	8	0	71	TP
	58	4	38	0	29	FN
	8	0	54	75	0	TN
	0	0	0	25	0	FP

Comments: TP=True Positive (the diagnosis given by the algorithm is "Positive", and the visual observation says it is "True"), FN=False Negative (a good registration is not seen by the algorithm), TN=True Negative, FP=False Positive.

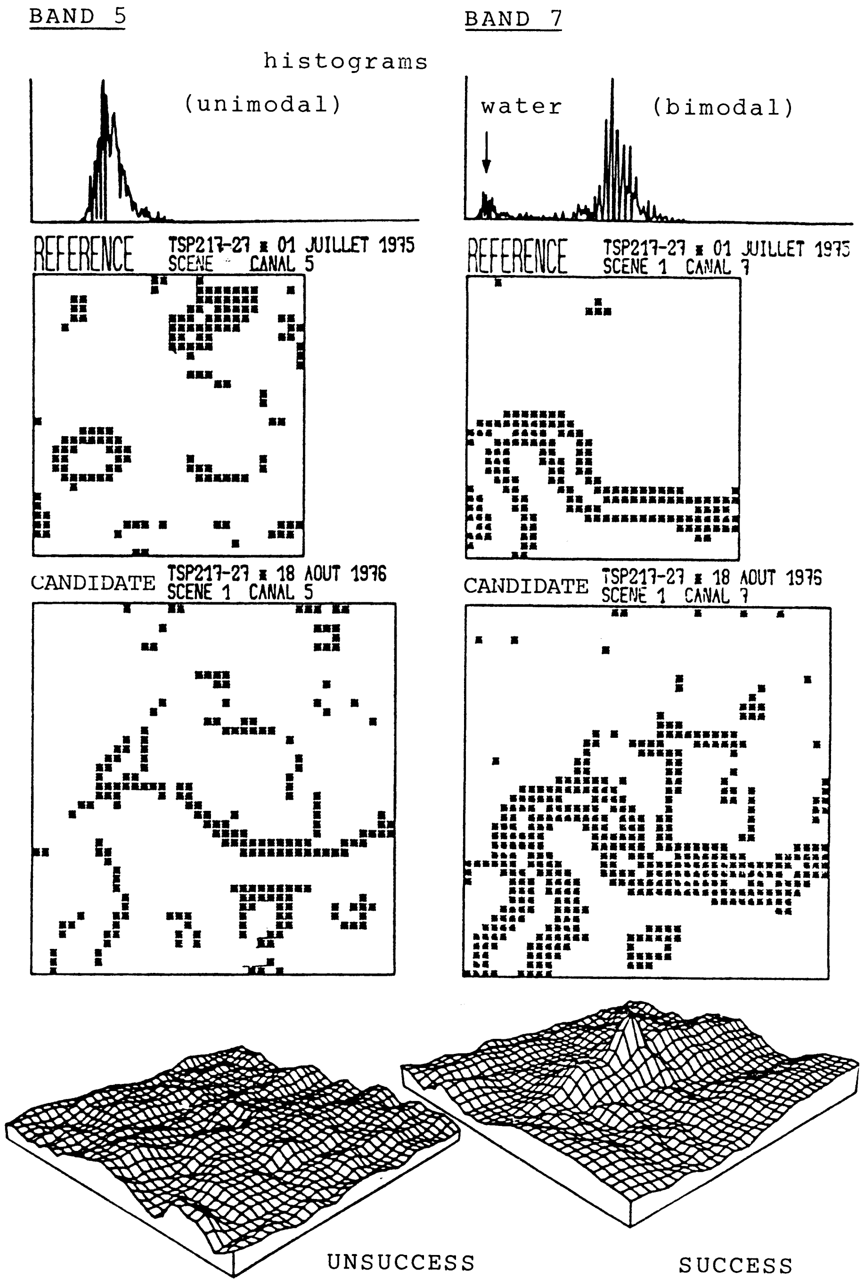
Obviously, the best is maximizing the TP rate and eliminating the FP, which is the worst case because a false location is recorded on the CATALOG.

We can notice that the band 5 yields the best contrasts and then the best discontinuities, at the end of Spring and in Summer (prevalence of chlorophylian activity). On the other hand, the band 7 is better in Winter and at the beginning of Spring (prevalence of bared soil).

Over a coastal area and, generally, every time there is a presence of water in the countryside, the band 7, which clearly discriminates land and water, is more efficient (see Figures 3.2(a) and (b)) .

All these results are in (12),tome II.

Figures 3.2. Influence of the Spectral Band



UNSUCCESS SUCCESS

4. THE "LAURAGAIS PROJECT":A LIVE EXAMPLE OF THE MULTI-CONCEPT.

The "Lauragais project" (13) is intended to vegetation monitoring by using both a data bank of ground truth measurements and a set of remotely sensed data taken by an airborne scanner: the DAEDALUS.

Ground data = canopy cartography, biological and structural characteristics of the different crops.
Remotely sensed data = eight spectral bands, ranging from 400 nm. to 1000 nm.,at each date. Two flights in 1978, five in 1979 and five planned in 1980.

Potentially, the Multi-Concept can produce a function:

for each pixel (i,j) $\longrightarrow$ $f(i,j) \in \mathbb{R}^{96}$
of a size of about
3 by 3 meters

96=8 bands by 12 dates!

The problem is to get the 12 images overlayed with a good accuracy.

4.1. Rectification by "Sliding Models":

Owing to the severe deformation, the rectification model cannot be computed by a polynomial over the whole image: even with a five degree, the residuals errors remain high (4 to 5 pixels RMSE, 20 pixels max.)
A better way is fitting local models along the plane track, according with the zones of flight stability (skew variations are the main causes of error).
The local models are linear panoramic ones (8 parameters, see table 4.1.), and the rectification is done by "sliding" from one model to the following, over an overlaying zone of 10% or 20% of each model (14).
The residual errors are notably lower: 1 to 2 pixels RMSE, 10 pixels max., but the Sliding Model computing needs so many homologous pixels that only the automated registration is able to do it (minimum number of pixels/local model 10, number of models/image 10, then about 1200 locating are requested for the 12 images)
The table 4.1. shows the different operations to work out for giving reality to the Multi Concept in this experiment.

Table 4.1. Operating Chart

- Choosing a Reference (image of best quality)

- Coarse estimating of the relative deformations between the Reference and each of the eleven other images: visual selection of 4 pixels on the Reference and their homologous = 48 visual locating (vs. 1200)

- Eleven automated registrations and recording of catalogs of control points

- Eleven computing of Sliding Models.

Description of the Sliding Model:

1. compute a linear regression line for all the pixels in the CW, which are the homologous of pixels of a same scan-line in the RW

it gives a simulated scan-line

2. estimating the parameters of a panoramic model between two simulated scan-lines

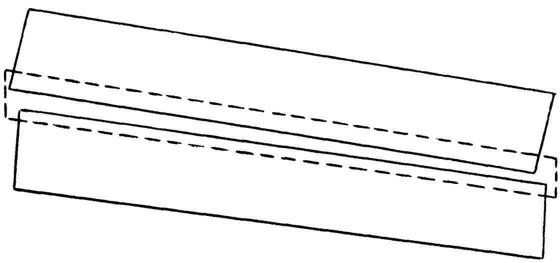
$$\begin{cases} u = P_1(x,y) = x_0 + \alpha x + \beta \,\mathrm{tg}((y-p_0)\Delta\omega) \\ v = P_2(x,y) = y_0 + \gamma y + \delta \,\mathrm{tg}((y-p_0)\Delta\omega) \end{cases}$$

$\alpha, \beta, \gamma, \delta$ are computed from estimations of:
- a relative skew,
- " angle,
- " speed,
- " altitude.

between the two flights

3. linear smoothing of the parameters between every couple of adjacent models

10% or 20% of overlaying →



4.2. Using the Sliding Models:

- field by field analysis:
the ground data are recorded field by field and not pixel by pixel, then the misregistration is not really a problem as well it does not exceed 2 pixels (there are few of greater misregistration).
Then we can merge the information of the ground data bank and the radiometric values of any field, at any date, in any spectral band, only by knowing each Sliding Model.
The Rectification itself is not necessary, we can get access to requested informations by the method of Self Defining Data Sets (SDDS = original radiometric information + geometric information, see (15)).

- SPOT-images simulation (16) :
the radiometric simulation is obtained from the eight bands of DAEDALUS and gives the three bands of SPOT, or the panchromatic band;
the geometric simulation is obtained by combining the spatial filter of the SPOT-radiometer, its flight model and the Sliding Model previously computed for every image.
Then the "LAURAGAIS Project" can be used as a performance valuer of the capabilities of SPOT for vegetation monitoring.

5. CONCLUDING REMARKS.

Recent work on image-to-image Registration is presented in this paper, with reference to the Multi Concept. Further studies should be done on several aspects of this problem, particularly on the a-priori selecting of reference windows, on the adaptability of discontinuity detection (automated selection of the best detector), on the computation of the model from the control points.

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