Three-dimensional exploitation of tandem imagery acquired with Libreville mobile station

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ABSTRACT

Alcatel Espace has been selected by ESA at the end of 1995, in the call for scientific proposals exploiting ERS SAR data received at the German transportable station in Libreville, Gabon. The proposal entitled "DEM computation by multiple methods using interferometry and cross-orbits" (AOL.F205) is performed in cooperation with IGN Espace and Elf Aquitaine.

The aim of the paper is to assess the quality of DEMs obtained with SAR interferometry during tandem operations. The method consists in the coupling of both interferometric ascending and descending couples to produce elevation maps. Because of the specific SAR geometry characteristics, two couples are used to reduce lay-over and shadow effects. In a second step, a space triangulation technique is conducted with the crossed stereopairs in order to produce a ground control point network which allows to improve the geo-location and calibrate absolutely the DEM.

The complete interferometric software including interferogram generation, orbital fringe correction, phase unwrapping and geocoding has been adapted to the above requirements.

The thematic objectives of the study, is to conduct an application on geology, to evaluate the potentiality of the technique, as a function of the different cover types, to derive the upper layer 3D profile, for oil extraction.

For this purpose, a set of data consisting of 16 images, was acquired over three different types of land cover [1]: Gabon (forest and mangrove swamps), Chad (sand desert and dunes) and Mali (sand and rocky pedestal).

The preliminary results show that the temporal decorrelation even with the one day interval causes strong disturbance in forested areas. Concerning the two other types of land cover, the first DEMs generated demonstrate the feasibility of the method.

1. Description of the interferometric chain [2]

A first step consists in the superimposition of the slave image in the geometry of the master image with classical radiometric sub-pixel correlation technique.

The second step consists in the generation of the interferogram, taking into account orbital fringe correction. This phenomena is linked to earth roundness and convergence/divergence of satellite orbits. This fringe network must be assessed and then substracted by modelling accurately the geometry of the scene acquisition.

We consequently developed a physical radar geometric model for the direct and inverse localization problem. This model uses orbital data (precise orbit i.e ORB.PRC products or the five ephemerides contained in the leader file) and is integrated with the GEOLIB library which is the recommended French D.O.D coordinate conversion library, which enables one to obtain a reference information relatively to any ellipsoid or geoid. In the sake of simplicity the results presented in this paper are referenced to WGS84.

Hence the mathematical formulation can be written as follows:

for a pixel P of the interferogram, the phase F p is obtained through:

$$Zp = A\exp(j\Phi p) = \frac{1}{N}\sum_{N} ZmZs^{*}\exp(-j\Phi c)$$

where the phase correction factor deduced from model is $\Phi c = \frac{4\pi}{\lambda}(Rm - Rs)$

and Rm = distance between satellite and point for the master image

Rs = distance between satellite and point for the slave image in the master image geometry.

The phase correction is calculated on a grid and extended to the whole image through the use of barycentric coordinates inside facets, covering the master image, assuming the model is linear with respects to these coordinates.

2. Phase unwrapping technique

The method that has been applied in our study is a classical least squares method which aims at determining an unwrapped phase minimizing the quadratic error between its gradient and the gradient of the measured phase. This integral method is a global method, with conditions at the limit (Neumann conditions) to ensure the unicity of the solution.

3. Relative height calibration

The altitude of ambiguity is then calculated using the ancillary data on a grid which is extrapolated using the same procedure as for the phase correction. The product of the unwrapped phase by the altitude of ambiguity scaled by the factor 2p leads to a relative D.E.M.

4. Absolute height calibration

The final D.E.M is obtained by introducing the offset of ground control points (whose coordinates are known in planimetry and in height) in the previous relative D.E.M.

The ground control points are determined by space triangulation technique using this time, ascending / descending stereopairs.

The sofware is implemented at IGN Espace in Toulouse and allows, only by taking homologous points between one ascending and one descending images (without any ground control points), to reach an absolute localization accuracy between 30 and 50 meters, an internal consistency of 20 meters for planimetry, and 5 meters for height [3], as explained in the following section.

5. SPACE TRIANGULATION TECHNIQUE

The technique has been tested on the Mali site where no accurate maps are available. Only 1:200000 scale maps, leading to approximately 200 meters planimetric accuracy, linked to the uncertainty related to the geodetic system, were found. In addition, it was hardly possible to identify ground control points between the radar images and the maps. But the identification of homologous points between images even in ascending and descending passes was feasible.

In this context, four homologous points were selected and identified in the four possible couple combinations between ERS1 and ERS2, by an experienced operator. The terrain coordinates of the points are estimated with an expected accuracy given in the paragraph n°4 and the couples were shown to be one another coherent within 35 meters in planimetry and 10 meters in altimetry.

The only difficulty remains in the validation of the whole procedure because of the lack of reliable topographic data. One solution could be to optimize the ERS localization physical model on an area of the same orbit, where the topography is known and to transport the geometry by space triangulation technique taking advantage of the geometric properties of ERS.

6. SELECTION OF DATA

In the frame of our project, we first selected 4 couples on the three different sites to assess the potentialities of interferometry as a function of cover types. The characteristics of the ERS1/ERS2 images are resumed in the following table.

Site	Pass	Baseline (m) (Bp,Bn)	Altitude of ambiguity (m)
Mali	Ascending	(-72,-151)	63
Mali	Descending	(92,143)	66
Chad	Descending	(-97,-281)	34
Gabon	Ascending	(-49,-107)	89

Table 1.a Orbital characteristics of interferometric pairs

Site	Pass	Instrument	Date of data take
Mali	Ascending	ERS1	18/04/96
Mali	Ascending	ERS2	19/04/96
Mali	Descending	ERS1	16/03/96
Mali	Descending	ERS2	17/03/96
Chad	Descending	ERS1	22/11/95
Chad	Descending	ERS2	23/11/95
Gabon	Ascending	ERS1	28/03/96
Gabon	Ascending	ERS2	29/03/96

Table 1.b Temporal characteristics of interferometric pairs

7. PRELIMINARY RESULTS

Concerning the Mali site, the fringe network is of rather good quality, allowing the generation of a D.E.M, where the large geological faults can be recognized on the interferograms and on the DEM (cf figures 1,2,3,4,5).

For the Chad site, the D.EM has been generated and the sand dunes are clearly illustrated (cf figures 6 and 7).

On the Gabon site, located in mangrove forests, coastal zone and Gabon river estuary, on the contrary, the large temporal decorrelation, even with the one day interval between passes, due to the water and the equatorial forest prevents from getting fringes with a sufficient signal to noise ratio. The city of Libreville is hardly recognizable in the middle lower part of the image (cf figures 8 and 9). The interferometric application is therefore limited on this kind of land cover.

8. CONCLUSIONS AND OUTLOOKS

In the frame of this study, we have developed and improved a complete chain which aims at extracting three-dimensionnal information from interferometric and radargrammetric radar images and combining both techniques.

Nevertheless the following tasks need to be performed for a complete and operational system: absolute height calibration by inserting the altimetric information into the relative D.E.M, optimal combination of cross-orbits interferograms to get rid of artefacts linked to radar geometry (shadow and lay-over effects) as well as atmospheric propagation distortions, quality control module for manual accuracy enhancement, in low coherence areas. For this purposes, a geometric software developed in the frame of an internal study entitled "Multipass Multitemporal Integration" will be used for co-registration and geocoding.

In the following phase, the geological application is to be performed in order to assess the possibility to infer relevant geo-physical parameters for oil extraction.

9. References

[1] The role of ERS SAR data for central african countries, A. Husson and J. Harms, ESA publications division, SP1199, June 1996.

[2] Radar interferometry: limits and potential, D. Massonnet and T. Rabaute, IEEE Transactions on Geoscience and Remote Sensing, Vol. 31, N°2, March 1993.

[3] Exploitation tridimensionnelle d'images ERS1, S. Sylvander, P. Gigord, Bulletin n°138, Société Française de Photogrammétrie et Télédétection.

Figures

Figure 1. Modulus of the product of intensities between ERS1 and ERS2, ascending pass on the Mali site.

Figure 2. Ascending pass tandem interferogram on the Mali site.

Figure 3. Modulus of the product of intensities between ERS1 and ERS2, descending pass on the Mali site.

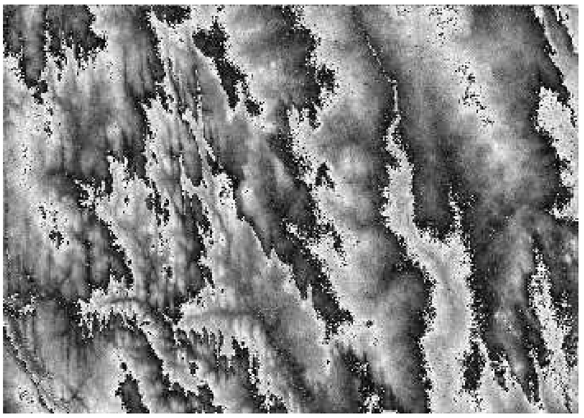

Figure 4. Descending pass tandem interferogram on the Mali site.

Figure 5. Relative digital elevation model generated from descending passes over the Mali site.

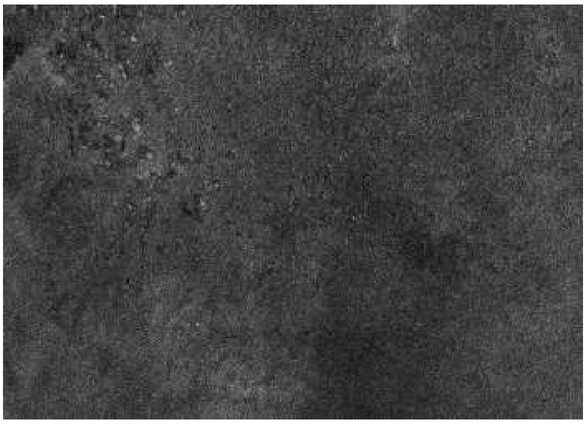

Figure 6. Modulus of the product of intensities between ERS1 and ERS2, descending pass on the Chad site.

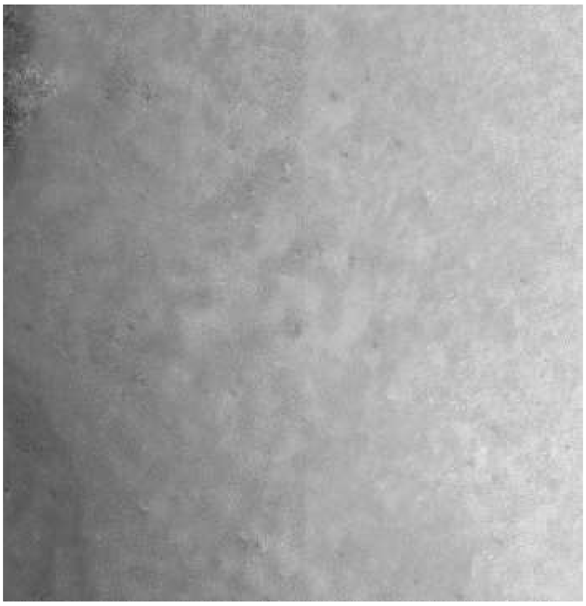

Figure 7. Relative digital elevation model generated from descending passes over the Chad site.

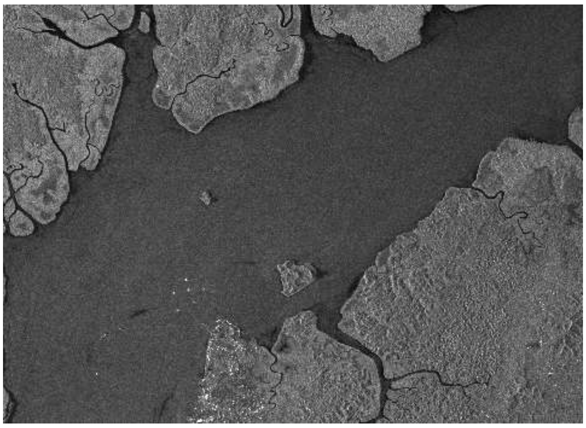

Figure 8. Modulus of the product of intensities between ERS1 and ERS2, ascending pass on the Gabon site.

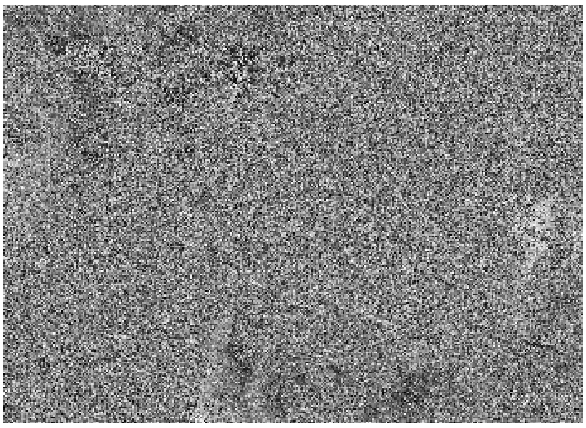

Figure 9. Ascending pass tandem interferogram on the Gabon site.

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