Interferometry process for satellite images SAR

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Abstract

The interferometry radar SAR (INSAR) is used in many application of the earth science, starting with the superposition of the couple of the images radar Single Look complex (SLC) and follows many step of the interferometry process which is presented in this paper. This work concerns the exploitation of radar images SLC of the Algiers area acquired on 03 January and 04 January 1994, the first is taken as master image and the other as slave. We have developed an interferometric process beginning with the implementation of a co-registration algorithm for our images, the elimination of flat-earth phase from the interferogram and at the end we developed a filter in order to minimizing the existing noise to have a good result in the final step of the process which is unwrapping step.

1. Introduction

SAR interferometry has been used as a first step in the realization of digital terrain models by Graham in 1974; it exploits the length difference of the wave's journey to and fro during acquisition of two radar images. In our work, we implemented the algorithm of co-registration to keep the common part between the two radar images (ERS-1 image acquired January 3, 1996 taken as a master and ERS2 image acquired on January 04, 1996 as the slave image) then we calculate the trajectories of the two radar to find the distance between them which is called baseline, it is used in one of our two algorithms implemented and applied to the interferogram to remove the flat-earth phase. The resulting interferogram is filtered to minimize noise, this step is elementary to unwrap the final phase.

2. The Interferometry theory

Radar interferometry is based on exploiting the phase difference of two images called master image (M) and slave image (S), acquired on the same area from two orbits separated by a known baseline distance B, see Fig1.

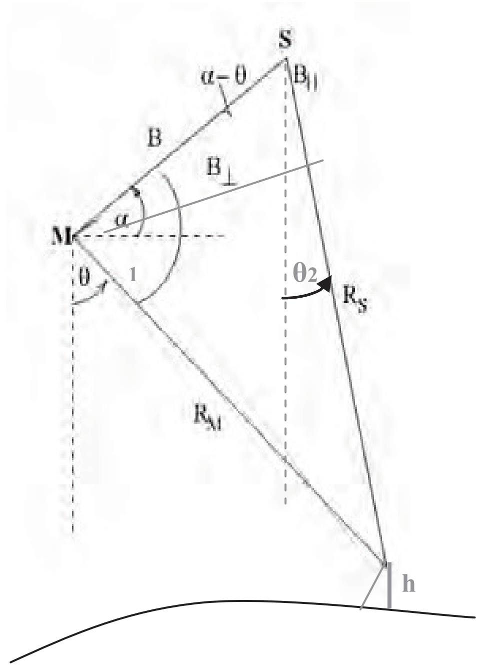


Figure 1. Radar Interferometry

$B_{//}$ et $B\perp$ are respectively the horizontal component and vertical component of the baseline, α is the tilt angel and θ is the incidence angel.

The phase of the target relative to the two acquisitions is:

$$\varphi_M = -\frac{4\pi}{\lambda} R_M + \varphi_{erreur M} \quad (1)$$

$$\varphi_S = -\frac{4\pi}{\lambda} R_S + \varphi_{erreur S} \quad (2)$$

R is the distance between target and satellite, Φ_{error} is the phase error due to signal delay caused by several phenomena (acquisition system, atmosphere etc ....).

The interferogram is obtained by this interferometric product:

$$S_M \times S_S^* = A_M.A_S.\exp\{\Delta\varphi\} \qquad (3)$$

S is the complex image.
A is the amplitude of the complex image.

The phase difference Δφ is expressed as:

$$\Delta\varphi = -\frac{4\pi}{\lambda}(R_M - R_S) + \Delta\varphi_{erreur} \qquad (4)$$

If we assume that the phase error of the two images is the same especially when the same satellite took the two images (double pass) and the atmospheric conditions are neglected. The phase difference becomes:

$$\Delta\varphi = \varphi_E + \varphi_{tpg} \qquad (5)$$

with : $$\varphi_E = -\frac{4\pi}{\lambda}B\sin(\theta_o - \alpha). \qquad (6)$$

$$\varphi_{tpg} = -\frac{4\pi}{\lambda}B_{\perp}d\theta \qquad (7)$$

This phase is divided into topographic phase which is proportional to the elevation and a flat-earth phase which is the result of the baseline and the radar acquisition.

3. The Interferometry process

The process developed has been tested on a couple of images acquired ERS1/ERS2 the 3rd and 4th January, 1996 from the Algiers region, the main steps of this process is shown in Fig. 2.

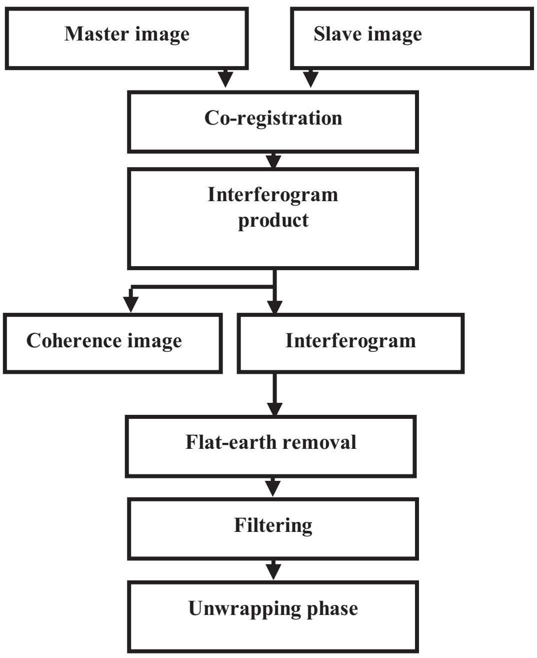


Fig. 2. Interferometry process.

3.1. Image coregistration

The interferometric information is the phase difference response from a target excited at two radar positions, master and slave positions. These two answers represent the radiometric value and the phase of the two pixels positioned on both positions.

To extract the phase difference of two pixels, it's necessary to have the two images superimposed. To achieve this overlap, first we extract the common area between the two acquisitions

To verify our results, we use the BEST program, which is an utility developed by the European Space Agency for handling data from ESA satellites namely ERS1 and ERS2, ENVISAT ASAR.

We took any point in one of two images, with their geographic coordinates, Latitude and Longitude; the coordinates in both master and slave images are respectively:

P (Xm, Ym) et P (Xs, Ys).

The offset gap between the two images is as follows:

Offset(X, Y) = P (Xm, Ym)-P (Xs, Ys) (8)

This operation is just a preliminary phase of the co-registration step. To get a good co-registration of the two images; we develop a method based on phase correlation. This method uses the Fourier transform properties to calculate the shift value [4].

Indeed, the Fourier transforms translate the displacement between the two images into a phase shift frequency in the spectral area. To calculate the translation between the two images, we have to observe the phase shift between their Fourier transforms. The latter should be a monochromatic wave, which is the translation vector [5].

3.2. Interferometry product

The similarity of the two radar signals can be measured by calculating the interferometric coherence, which is the normalized complex correlation

$$\gamma = \frac{< S_m \, S_S^* >}{\sqrt{< |S_m|^2 >< |S_S|^2 >}} \qquad (9)$$

$|\gamma|$ Varies between 0 in the case of decorrelation, and 1 if the two signals are perfectly correlated. The phase of this expression is the phase difference of two signals backscattered by targets; it is given by an image called interferogram. This phase is given modulo 2π and represented in the image by fringes.

3.2. Flat earth removal

3.2.1. Baseline calculation

As mentioned previously the baseline is the key parameter to choose the interferometric pair (master and slave image). For this, we developed a procedure to estimate the baseline value. First we interpolated the two orbits corresponding to the two images using Lagrange interpolation, so we used the 05 points in the data file header of the two images.

The baseline is calculated by this equation:

$$B = \sqrt{(X_S - X_M)^2 + (Y_S - Y_M)^2 (Z_S - Z_M)^2} \quad (10)$$

The two radar positions, master (Xm, Ym, Zm) and slave (Xs, Ys, Zs) correspond to the same point in both master and slave images

Two approaches for estimating the flat-earth phase are relevant here. The first is based on the interferometric geometry, the second is based on the Fourier transform.

3.2.1. Geometric method

This Phase, caused by the ellipsoid reference, can be estimated using information from the two orbits, and after the orbital fringes or the flat-earth are generated by (11) and subtracted from the raw interferogram

$$\varphi_E = -\frac{4\pi}{\lambda} B\sin(\theta_0 - \alpha). \quad (11)$$

3.2.1. By the Fast Fourier transform

This method relies on the detection of the orbital frequency of the fringes which are regularly repeated, by detecting the maximum amplitude in the spectral plane, and after we deducted its position along both horizontal and vertical axes. The ratio of the horizontal and vertical position calculated from the maximum image size (number of columns and rows) respectively gives us both horizontal and vertical frequency of the orbital fringes, and this allows us the generation of these fringes and their subtraction directly from the raw interferogram. .

3.3. Interferogram filtering

The interferograms generated are often characterised by noise, the origins of these are different: the speckle which is the result of the spatial and temporal de-correlation between the two images, and geometric distortions due to relief…etc.

For a better exploitation of the topographic phase, we must reduce the noise in the interferogram [6], so we filter the interferogram with an appropriate filter.

We used the filter vector which is based on averaging over a 3x3 window size of both cosinus and sinus images created from this interferogram. And it is given by the following equation:

$$\hat{\varphi}_{n,m} = \arctan(\sum \sin\varphi_{i,j}, \sum \cos\varphi_{i,j}) \quad (12)$$

3.4. Phase unwrapping

The phase is only known modulo 2π, therefore it is necessary to determine the multiple of 2π to add to the measured phase φ_{mes} on each item to obtain an estimate of the actual phase φ_{abs} [6], [7],see Fig. 3.

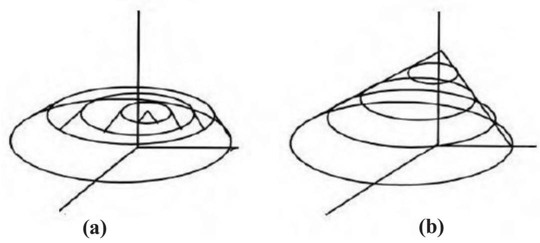


Fig. 3. Phase unwrapped.

a. initiale mesured phase.
b. absolue phase.

4. Data used and results

In our work, we used a pair of radar images of tandem ERS1-ERS2 type SLC (single look complex image) of the Algiers region. Their characteristics are given in the following table:

Table 1. Data used

Mission tandem ERS		
Satellite	***ERS1***	***ERS2***
Produit type	SLCI	
Date	03/01/1996	04/01/1996
Orbite	23371	3698
Station of reception	Italian -PAF	Italian -PAF
Mode	Descendant	Descendant
Doppler frequency	386 Hz	
Frame	2871	
Track	00337	
Basline	190m	
Size	4900*26581 pixels	4900*2654 4 pixels

To extract the common area between the two images (master and slave image), the offset value is calculated thus:

Offset of left-right shift is 15 columns.
Offset of high-low shift is 148 lines.

Using the BEST software, the offset calculated is 159 rows and 11 columns, and the gap between the two results is justified by the estimation errors.

After we applied the phase correlation in order to have a good superposition, we calculate the product interferometric cited previously. Coherence image, interferogram and the result are given in Fig. 4.

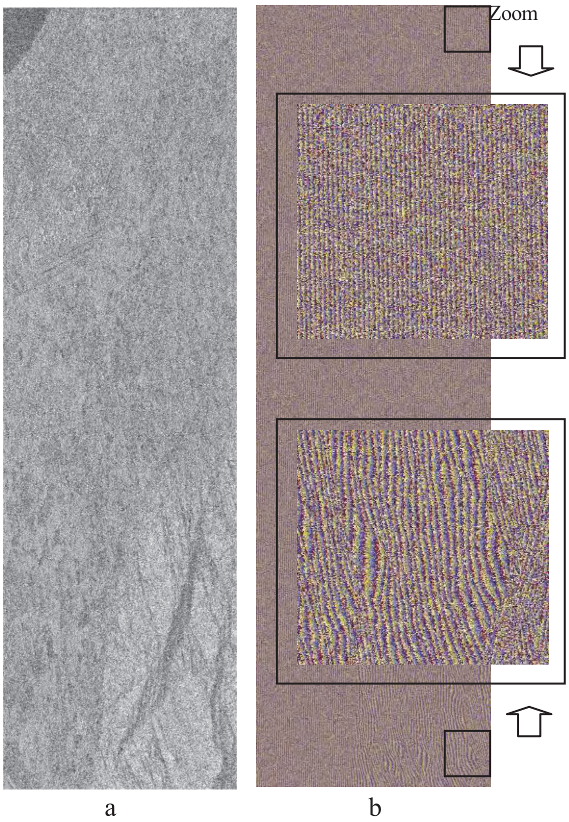


Fig. 4. Interferometric product

a. Coherence image
b. Interferogramme.

The interferogram generated couldn't be operational, each pixel is a sum of a topographic phase useful in interferometry and flat-earth phase; so we need to eliminate the last element by the two methods mentioned previously.

The baseline calculated is: 207 m
The two components, horizontal and vertical, of the baseline are:

$$B_{//} = B\sin(\theta_0 - \alpha) = 54{,}46\text{m.}$$

$$B_{\perp} = B\cos(\theta_0 - \alpha) = 200\text{m.}$$

Knowing the two angles, α has a value of 8 ° and the viewing angle θ_0 is 20.54 °, we can simulate the flat-earth phase and remove it from the raw interferogram.

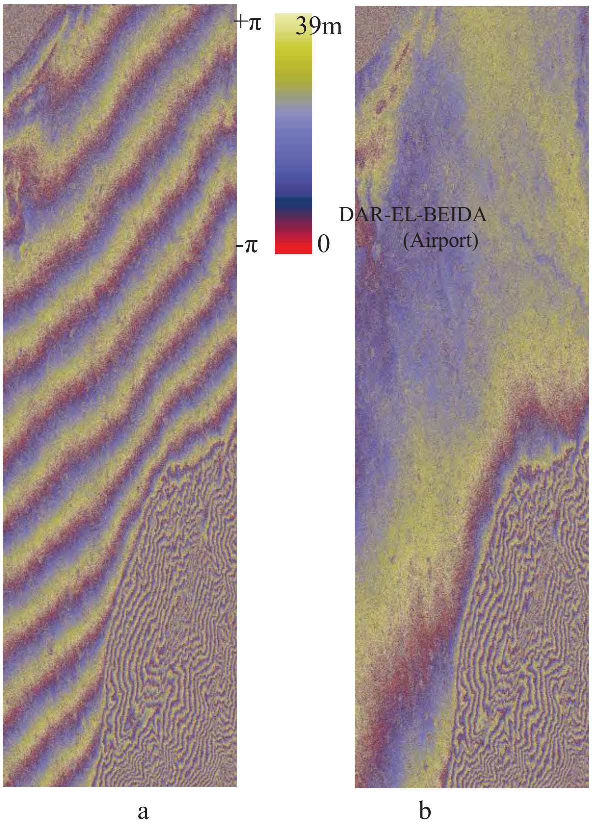


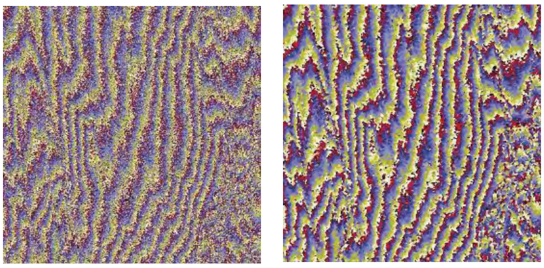
Fig. 5. Orbitale fringes removal

a. Geometric method
b. FFT methode.

Fig. 5, shows that the method based on FFT is more accurate than the geometric method.

The result obtained by the geometric method shows lot of fringes around the area of Dar El-beida airport which is a flat area (Fig. 5-a). However, the interferogram corrected by our method, which is based on the FFT method, gives one fringe in the same region (Fig. 5-b).

Before proceeding with the unwrapping step, we must reduce the noise existing in the resulting interferogram by using the vector filter. The Fig. 6 represents the intreferogram before and after filtering.



a b

Fig. 6. Interferogram filtring

a. Raw interferogramm.
b. Filtered interferogram.

5. Conclusion

Our work shows how to develop a part of the interferometric process which is useful for generating a digital elevation model (DEM). Beginning with the offset shift calculated between the two images, a master and a slave image, and applying the registration step to have a good superposition. Then, we generated the interferometric products, the coherence image and the raw interferogram. The latter is used in the unwrapping phase step after the flat-earth removal and filtering are finished.

5. References

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