

# Sub-pixelic Image Registration for SAR Interferometry Coherence Optimization

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**Abstract**— This paper presents a methodology for the registration of an Interferometric Synthetic Aperture radar (InSAR) pair images with a sub-pixelic precision performed in the Fourier domain, using the Fast Fourier Transform (FFT). We look for the maximum of the modulus of the cross-correlation coefficient of both images on a window dimensions of 2x2 pixels using an iterative process. This will be possible in the Fourier domain, since a shift in the spatial domain is achieved by a multiplication with an exponential factor (which is the real shift less than one pixel) in the frequency domain. It is shown that the proposed sub-pixelic approach allows the coregistration of the images with an accuracy up to a tenth of a pixel (and even less).

## I. INTRODUCTION

SAR interferometry has become one of the most important techniques of relief mapping [1], [2], [3], [4]. The accuracy of digital elevation models (DEMs) produced by SAR interferometry are generally comparable to reference DEM [6](obtained from a SPOT stereo pair or from an official data base) and ground control points taken over the relief. However, this is true under certain conditions of the ground scattering characteristics and the acquisition (sensor, baseline, ...) geometry which could be measured via the interferometric coherence [9], [10], [17].

In practice, the coherence has to be estimated on a coregistered images from the combination of several pixels (N independent samples correspond to the pixel or to an area around this pixel) to limit statistical errors [7], [8]. In order to tend to unbiased coherence estimation, a large estimation window is required at low interferometric correlation. We must coregister one image (the slave one) with respect to the other (the master one). As a result of the coregistration, we get the best bilinear transform that must be applied to the slave image to make it superimposable to the master one. In generally, the coregistration process is performed on two steps : a coarse one, where the shift (integer number of pixels) between the two images in range and azimuth is computed, and than a fine one, where the computed shift is less than one pixel.

In this paper, we present a new procedure for sub-pixelic fine coregistration performed in the Fourier domain, using the Fast Fourier Transform (FFT). We look for the maximum of the modulus of the cross-correlation coefficient of both images on a window dimensions of 2x2 pixels using an iterative process. This will be possible in the Fourier domain, since a shift in the spatial domain is achieved by a multiplication with an exponential factor (which is the real shift less than one pixel) in the frequency domain. It is shown that the proposed sub-pixelic approach allows the coregistration of the images with an accuracy up to a tenth of a pixel (and even less).

The proposed algorithm is tested on two different areas: a highly energetic relief zone (Mustang-Nepal) and a flat zone (Orgeval-France). It is shown that on stationary region, the algorithm is well adapted and gives important results. However, non stationary regions are time consuming and the result is random.

## II. INSAR IMAGE CO-REGISTRATION

To obtain a high quality DEM from InSAR, the complex images need to be registered to sub-pixel accuracy. Image coregistration techniques allow the determination of a geometric transformation which may exist between two images  $s$  and  $m$ . In general cases, image matching depends on three parameters : translation, rotation and scaling. For interferometry SAR (InSAR), we generally obtain satisfactory results with only sub-pixel translation registration.

An InSAR image couple is a pair of two SAR images where every image is a bidimensional array of single look complex (SLC) data (focused data) resulting from the processing of raw data in range and in azimuth. These two SLC images result from the raw data focusing. Their registration implies compensation of azimuth and range pixel displacement. Note that the slant range and azimuth offsets change along track and across track in the SAR SLC images.

The InSAR coregistration process is performed on two steps using local statistical information (magnitude or phase) computed with selected windows on both images [5], [2], [15] :

- Coarse matching, where the integer shifts (translation) between the two images in range and azimuth are computed. This could be done by cross-correlating the amplitudes of the images [5] or maximizing a spectral signal to noise ratio ( $SNR$ ) [2] on a selected windows with integer positions [13], [14].
- Fine matching, where the computed shifts (in range and azimuth) are sub-pixelic.

However, in the case of fine matching, the sub-pixel cross-correlation and  $SNR$  maximisation is not robust in the spatial domain against correlated noise and disturbances [15], [16], [18].

## III. SUB-PIXELIC INSAR REGISTRATION

Let  $s(x_s, y_s)$  and  $m(x_m, y_m)$  represent the two complex images of the InSAR pair to be coregistered. If  $s(x_s, y_s)$  is a translated replica of  $m(x_m, y_m)$ , then the transformation matrix can be written as follows:

$$\begin{pmatrix} x_s \\ y_s \end{pmatrix} = \begin{pmatrix} x_m \\ y_m \end{pmatrix} - \begin{pmatrix} \eta_x + \varepsilon_x \\ \eta_y + \varepsilon_y \end{pmatrix} \quad (1)$$

TABLE I  
DATES AND PERPENDICULAR BASELINES OF THE CONSIDERED  
ERS-1/ERS-2 INTERFEROMETRIC TANDEM PAIR.

	Mission	Orbit	Date	$B_{\perp}$
Orgeval	ERS1	22956	05/12/95	0
	ERS2	3283	06/12/95	83 m
Mustang	ERS1	25422	25/05/96	0
	ERS2	5749	26/05/96	90 m

where  $\eta_x$  and  $\eta_y$  are the azimuth and the range integer translation factors and  $\varepsilon_x$  and  $\varepsilon_y$  are their corresponding sub-pixel translation factors.

In order to realign images  $s$  and  $m$ , it is first necessary to determine the integer translation vector  $(\eta_x, \eta_y)$ . For this, several image registration algorithms could be used to solve this problem [11], [12], [19]. We used the ISAR software (the *CoherRegist* subroutine) distributed by ESA (European Space Agency) [19] to compute these integer coarse shifts. Then, we perform an a priori registration using the resulting a priori coarse coefficients.

The present paper is meant as a contribution to the estimation approach of the sub-pixelic translation vector  $(\varepsilon_x, \varepsilon_y)$ . We consider for the following the transformation model of (1) between a two InSAR images  $s(x_s, y_s)$  and  $m(x_m, y_m)$  to be matched. Thus, using the ISAR software, we perform an integer co-registration of  $s$  and  $m$ , which lead to a new relationship between the coregistered image  $s'$  and  $m$ :

$$s'(x, y) = m(x - \varepsilon_x, y - \varepsilon_y) = m(x, y) \otimes \delta(x - \varepsilon_x, y - \varepsilon_y) \quad (2)$$

where  $\otimes$  is the convolution operator and  $\delta$  is the dirac function. Our idea consists in looking for the vector  $(\varepsilon_x, \varepsilon_y)$  that maximises the cross-correlation between  $s'$  and  $m$ . However, in order to reduce the complexity given by the convolution in the spatial domain, we consider equation (2) in the Fourier domain:

$$S'(u, v) = \exp(-2j\pi(u\varepsilon_x + v\varepsilon_y)) M(u, v) \quad (3)$$

where  $S'$  and  $M$  are respectively the Fourier transform of  $s'$  and  $m$ .  $\varepsilon_x$  and  $\varepsilon_y$  are taken in the interval  $[-0.9, +0.9]$  (a window of  $2 \times 2$  pixels) with an incremental step of 0.1. The cross correlation is computed locally on a window size of  $3 \times 3$  pixels. The corresponding shift matrix is given by:

$$D = \begin{bmatrix} 1 & e^{-2j\pi\varepsilon_y} & e^{-4j\pi\varepsilon_y} \\ e^{-2j\pi\varepsilon_x} & e^{-2j\pi(\varepsilon_x + \varepsilon_y)} & e^{-2j\pi(\varepsilon_x + 2\varepsilon_y)} \\ e^{-4j\pi\varepsilon_x} & e^{-2j\pi(2\varepsilon_x + \varepsilon_y)} & e^{-4j\pi(\varepsilon_x + \varepsilon_y)} \end{bmatrix} \quad (4)$$

For different values of  $\varepsilon_x$  and  $\varepsilon_y$  and for each pixel, we operate the product of the shift matrix with the corresponding neighborhood pixel matrix. Then, we compute the inverse Fourier transform of this product which will give the spatial cross-correlation factor.

On Fig. 1 are plotted an example of histograms of the azimuth and range shifts computed with the new algorithms from two different SLC images (detailed information on the used images are given in next paragraph).

#### IV. EXPERIMENTAL RESULTS

Two test sites representing different geomorphological regions are selected in order to test the robustness of the new sub-pixelic matching approach. The test areas are Orgeval (France,  $48^{\circ}51' N$ ,  $3^{\circ}08' E$ ) and Mustang (Nepal,  $29^{\circ}12' N$ ,  $83^{\circ}55' E$ ) (see Table I).

The Orgeval site is a rather flat area where the elevation varies from 120 m to 200 m. In this region, there are many agricultural

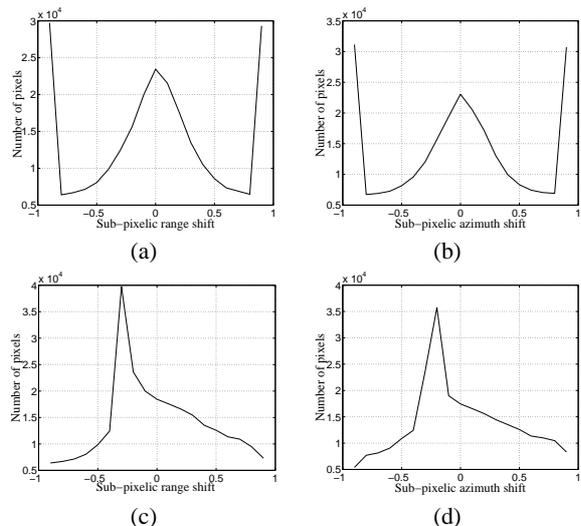


Fig. 1. Examples of histograms of the azimuth and range shifts computed with the new algorithms from (a) & (b) the Mustang and (c) & (d) Orgeval tandem pairs.

field and few urban areas which are located at the border of the test site. About 60% of the total area is covered by crops (wheat, corn, peas, flax, sugar beet) (Fig. 2 (a)).

The Mustang test area is a highly energetic relief site where the elevation varies from 3200 m to 4400 m. Cultivated land is rare and particularly low and vegetations are scattered. The villages on the selected area are small and without any particular shape. The Mustang site is a good test area for InSAR topographic Mapping, since it offers a big relief diversity (Fig. 2 (b)).

The coherence map of Orgeval indicates that more than 70% of the area has a coherence greater than 0.7. For the Mustang test site, although the ERS SAR data are acquired with 1 day interval between acquisitions, the corresponding coherence map (Fig. 2 (d)) computed with a  $(5 \times 8)$  pixel window indicates that only 50% of the samples have a coherence greater than 0.6. This is due to the energetic relief of Mustang. Moreover, after achieving the coarse registration using the ISAR software on the two tandem pairs (results are given in TABLE II).

Thus, we can understand the random results in Fig. 1 (a) and (b) where the sub-pixelic shifts are not dominante in range and azimuth. However, in Fig. 1 (c) and (d) in both azimuth and range direction, the sub-pixelic translation factors are dominante and we decide to co-register the tandem pair of Orgeval using these globale shifts.

TABLE II  
THE ESTIMATED MATCHING PARAMETER: THE INTEGER SHIFTS  
COMPUTED WITH THE ISAR SOFTWARE AND THE SUB-PIXELIC ONES  
COMPUTED WITH THE NEW ALGORITHM

	Orgeval	Mustang
<i>Parameters computed with the ISAR software</i>		
Azimuth shift [pixels]	1	-4
Range shift [pixels]	1	3
<i>Parameters computed with the new algorithm</i>		
Global sub-pixel azimuth shift ( $\varepsilon_x$ )	-0.2	-0.9
Global sub-pixel range shift ( $\varepsilon_y$ )	-0.3	-0.9

Performance evaluation of the sub-pixelic registration algorithm is done by comparing the coherence maps before and after the sub-pixelic matching approach. We conclude that the new sub-pixelic

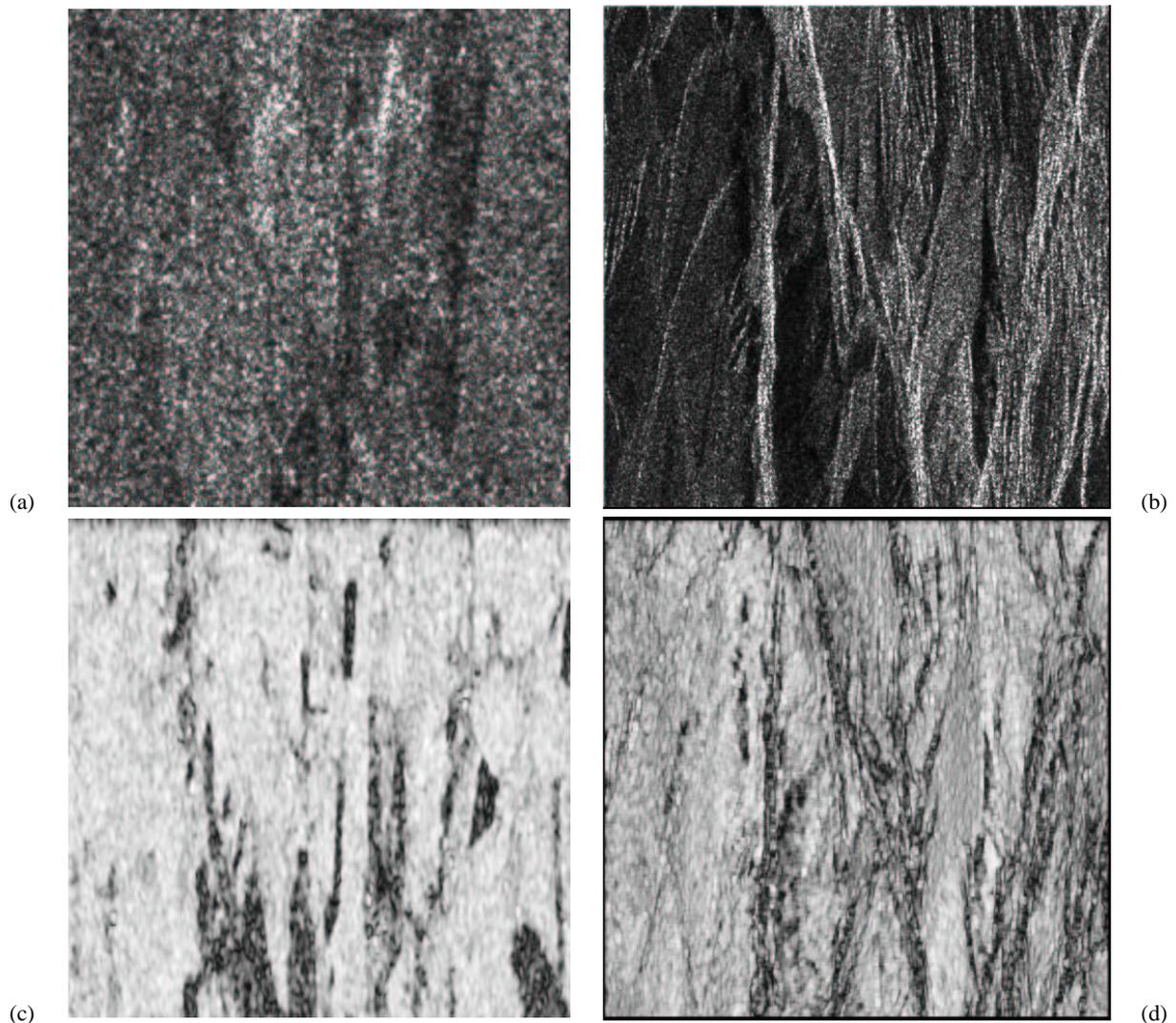


Fig. 2. SLC ERS interferometric pair tandem of (a) Orgeval and (b) Mustang and their corresponding coherence image (c) and (d). The coherence maps were computed with the ISAR software.

registration approach increase the number of coherent pixels and then the number of exploitable pixels for interferogram unwrapping. Elevation error estimation could be a good test for the validation of the developed algorithm. As we don't have some reference points on the test sites we couldn't achieve this test.

#### V. CONCLUSION

In this paper we developed a new approach, based on two steps, for the registration of an InSAR pair images with a sub-pixelic precision performed in the Fourier domain, using the Fast Fourier Transform (FFT).

First, using the ISAR software, we perform an integer co-registration (coarse) of the interferometric pair. Then, we look for the sub-pixelic translation factors that maximises the cross-correlation between both images on a window dimensions of 2x2 pixels using an iterative process. However, in order to reduce the complexity given by the convolution in the spatial domain, we consider the transform model in the Fourier domain.

This will be possible in the Fourier domain, since a shift in the spatial domain is achieved by a multiplication with an exponential factor (which is the real shift less than one pixel) in the frequency

domain. The new algorithm was tested on two different kinds of interferometric pairs with different coherence map. In the case of coherent pair the algorithm gives satisfactory results. However, the local computed offsets are not reliable when the InSAR images contain decorrelated zones, shadow zones or layover.

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