Options for High-Precision Motion Compensation for Airborne Differential SAR Interferometry

A. Reigber[1], P. Prats[2,4], R. Scheiber[3] and J.J. Mallorqui[2]

[1] Technical University of Berlin, Department of Photogrammetry and Cartography, Germany. Email: anderl@fpk.tu-berlin.de
[2] Universitat Politecnica de Catalunya (UPC), Dept. of Signal Theory and Communications, Spain. Email: pprats@tsc.upc.es
[3] German Aerospace Center (DLR), Microwaves and Radar Institute, Germany. Email: rolf.scheiber@dlr.de
[4] Universitat Autonoma de Barcelona (UAB), Dept. of Telecommunications and Engineering Systems, Spain

***Abstract*— In recent years, differential interferometry using space-borne SAR sensors has become an established technique for detecting and monitoring centimetre-scale deformations of the earth's surface, as well as glacier flows and land slides. Although often very efficient, the use of space-borne SAR data has several drawbacks, namely phase artifacts caused by atmospheric effects and very low coherence due to long data acquisition intervals. Airborne sensors on the other hand may overcome most of the problems mentioned above and provide a much higher flexibility in sense of spatial resolution, used wavelength and data acquisition. However, the use of airborne sensors has been prevented by insufficiently accurate motion compensation of the sensor platform.**

In this paper, the performance and deficiencies of the different approaches for estimation of residual motion errors are compared and evaluated, in the face of their application in airborne differential SAR interferometry. Some preliminary results of airborne differential SAR interferometry, obtained using an optimised motion compensation scheme, will be shown, too. The analysis carried out in this paper is based on repeat-pass interferometric data acquired by DLR's experimental SAR system (E-SAR) in L-band.

I. Introduction

The principal idea of differential SAR interferometry is to analyse phase effects in SAR interferograms, which are not related to the terrain topography. In general the interferometric phase difference between two SAR images taken at different times and from slightly different positions can be expressed as the sum of a systematic component, a component due to the terrain topography and a differential phase component $\Phi_{\Delta r}$, caused by changes in the path-length between the two acquisition times.

In differential interferometry, $\Phi_{\Delta r}$ is estimated by subtracting the systematic component, as well as the topographic component, by using an external DEM or a second interferogram free of differential effects. Recently, there have been some efforts to implement differential SAR interferometry also for the airborne case. In this case, the term $\Phi_{\Delta r}$ mainly consists of two contributions, one caused by displacements of the scattering centre and one caused by displacements of the sensor platform.

Therefore, the generation of interferograms using airborne sensors requires a very accurate compensation of the deviations of the aircraft from the ideal straight flight track. It has been proven that motion errors of up to some tens of meters can be compensated by advanced processing algorithms as long as the errors are precisely measured. However, current navigation systems provide only a position accuracy of about 5-10 cm. Therefore, in L-band, phase errors of up to 2π can be expected.

It is necessary to develop methods for estimating these unknown residual motion errors. In the following, three different approaches will be presented and discussed.

II. Residual Motion Compensation

A. Integration of the coregistration function

One possibility for estimating residual motion errors is the integration of the coregistration function of the interferometric pair [1]. It is based on the fact that residual motion errors are causing azimuth displacements in the image, which are measured during the coregistration of the interferometric image pair. Measuring the coregistration function in azimuth $\Delta x(x)$, the total residual motion error in the interferogram $\Delta r(x)$ can be estimated by integrating the azimuth offset over azimuth:

$$\Delta r(x) = \int_0^x \frac{\Delta x(x')}{r_0} \mathrm{d}x' + C \qquad (1)$$

Except for an integration constant C, which corresponds to a global baseline offset, this function can be obtained from the data itself. The unknown baseline offset can be estimated using ground control points, if available. The baseline error is typically given by the precision of the navigation system, i.e. about 5-10cm.

The crucial point of this method is the precise estimation and integration of the coregistration function. As in differential interferometry usually at least one interferogram has a long temporal baseline, one has to deal with low coherence in general as well as complete loss of coherence in some areas. To avoid errors, a very robust and precise coregistration method has to be applied. Currently a two-step algorithm is being used, consisting of a robust first order coregistration based on speckle correlation, followed by a second order coregistration based on the spectral diversity method [2].

B. Tracking of point scatterers with multisquint processing

Differently, the residual motion correction can be carried out by obtaining the phase of single scatterers observed from different azimuth positions. For a given scatterer, its phase versus azimuth position should show no variations. However, if residual motion errors are present, a variation can be noted, which is directly related to the residual motion errors [3][4].

The method consists of processing both master and slave images with different squints, so that each scatterer is observed from a different track position. Note that this approach can only be applied to SAR systems characterised by a relatively wide antenna beamwidth, as is the case of the DLR's E-SAR. A second option based on subaperture processing is under investigation. After coregistration (if needed), interferogram generation and coherence computation the scatterers can be selected depending on its mean coherence along the whole set of interferograms. Then, the phase versus along track position of each pixel can be computed. Note that we are not interested in the absolute phase, so instead of taking a reference phase, we can directly compute the difference between consecutive squints. Furthermore, if we divide this difference by the distance between both squint geometries, we are computing the derivative along azimuth. After averaging the derivatives in those points where the curves overlap the integration will result in the residual motion error.

Three important aspects of the method must be taken into account. First, the number of different squint processed image pairs must ensure there exist no blank spaces between pixel phase curves along azimuth so that the derivative is continuous. Secondly, the separation between squints must be small enough to ensure the variations are sampled fast enough [3] (results have shown a separation of one degree can detect in a satisfactory way the phase undulations). Finally, the selected coherence threshold is important in order to obtain satisfactory results. A too high threshold might imply the obtaining of insufficient pixels, while a too low one might imply most of the pixels are mainly noise.

C. Using DEM information

Compared to the methods presented before, the use of external DEM information provides additional compensation possibilities. As we are talking about repeat-pass interferometry, large phase errors occur due to the assumption of flat terrain for motion compensation. These errors can be compensated for each acquisition separately as external DEM information becomes available [5]. With respect to differential displacement measurements there is a simple way to use the DEM as a reference to eliminate the topography from interferometric image pairs. In this case, displacements of resolution cells may be evaluated from just one single interferometric image pair. However, this approach is not very accurate since the DEM may not be acquired from the same sensor in the same geometry, resolution and wavelength. Therefore, we propose to use at least three acquisitions in the same geometry to perform the differential evaluation, as was first suggested in [6].

Even in this case external DEM information can favourably be used to estimate the unknown phase constant in Eq. 1. Recall, that constant baseline errors cannot be found directly using the integration approach suggested in section II-A. In order to obtain valid estimates, the DEM information is backprojected into the slant range geometry of the master data and simulated interferograms are computed using the information from the reference tracks of each interferometric pair. These simulated interferograms are then compared to the actual ones. Their difference is evaluated only for high coherence areas. For X, C and L-band these are those areas dominated by surface scattering, where the scattering centres are considered to be very similar (no penetration into the volume). From these valid areas an averaged phase correction curve can be computed along the range dimension, which is suitable for the determination of the baseline offset errors. In this way, the approach is considered to complement the two approaches presented before in sections II-A and II-B in an optimum way. The simulated interferograms are useful also for efficient and stable phase unwrapping. A further benefit is, that no additional ground control points must be evaluated to estimate the absolute phase, which is required before starting any differential phase evaluation. The complete method sketched in this subsection is presented in more detail in [7].

III. Discussion

Three different methods for residual motion compensation have been presented, each of them with their own particular advantages and disadvantages. The integration of the coregistration function is a quite promising approach, which has its main limitations in the precision and spatial resolution of the used coregistration method. When low-coherent interferograms are involved the integration step can be challenging, as the one-dimensional integration of Eq. 1 can quickly produce propagation errors. A more robust two-dimensional integration scheme would be necessary here. High noise level caused by low coherence is another problem of this method.

Tracking of point scatterers seems to be better suited for processing low-coherent data sets as it depends only on a sufficient amount of isolated coherent points. However, an important restriction is that the SAR system must have a wide antenna beamwidth to allow for different processing squints. As the first method, it is not able to measure the total baseline offset.

Another approach is the evaluation of DEM information, possibly acquired by an additional single-pass interferometric flight. It can be used to evaluate the baseline offset and is therefore a perfect complement of the first two methods. In any case, the acquisition of some kind of DEM information is indispensable for differential interferometry, consequently this method does not represent any additional expense.

In Fig. 1 preliminary results, using only the first methods, are shown. In practice, an application of a combination of all the three methods is desirable. This is an ongoing work. First results will be presented on the poster, demonstrating

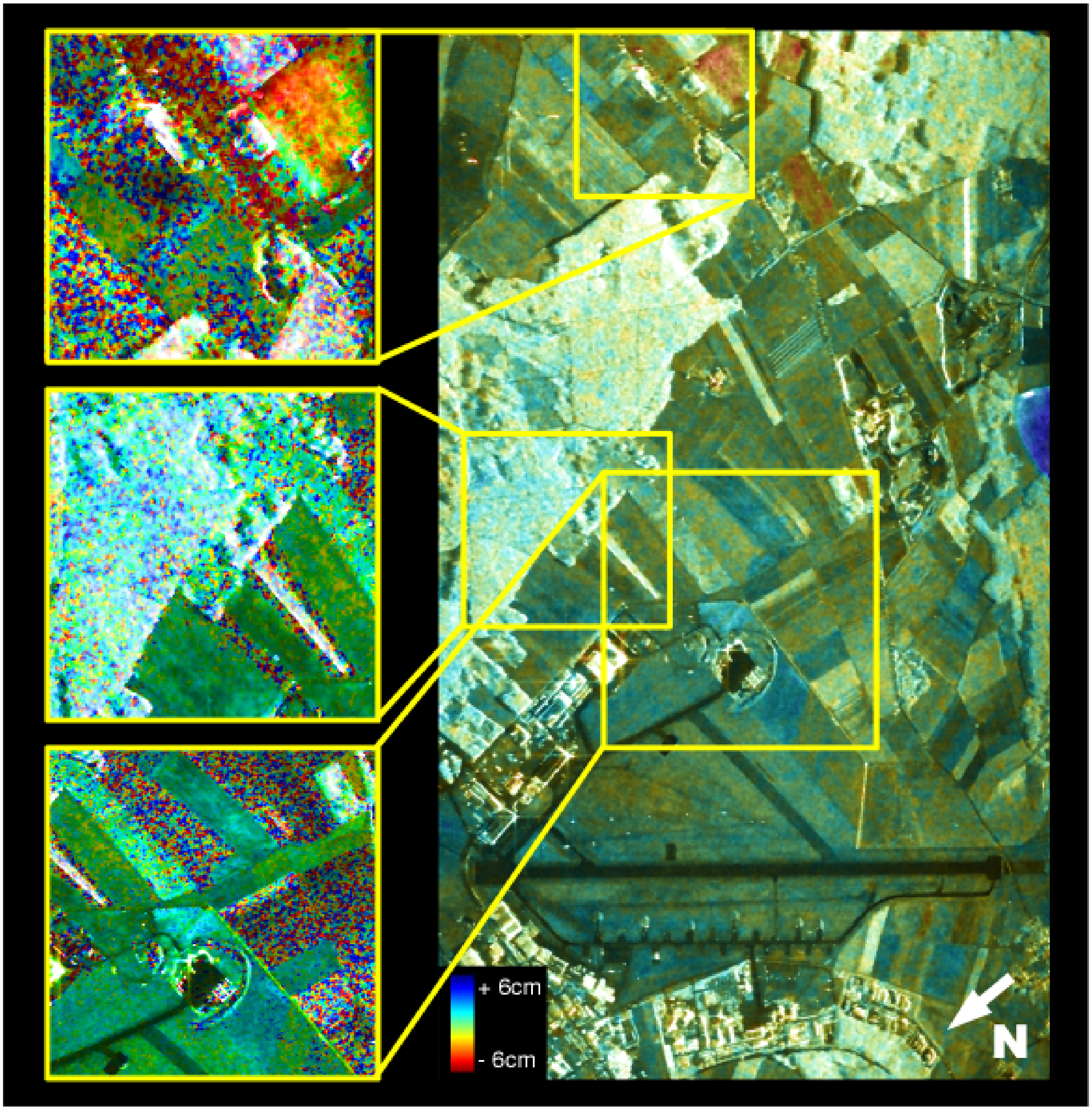

Fig. 1. Overlay of SAR amplitude (magnitude) and differential interferogram (colour) obtain at the Oberpfaffenhofen test-site, obtained by using the coregistration integration method. Temporal baseline: 336 days. The differential phase corresponds to displacements in line-of-sight direction from -6cm (red) to +6cm (blue). Left side: Magnification of 3 areas of interest.

the feasibility of airborne differential SAR interferometry. However, future work has to be done to improve overall robustness of the data processing.

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