Merging of the stereogrammetry and interferometry techniques as relative bandwidth grows. Illustration with VHF Carabas SAR images.

Hubert M.J. Cantalloube, Élise Colin-Koeniguer
Département Électro-Magnétisme et Radar
Office National d'Études et Recherche Aérospatiales
Palaiseau, France

P.O. Frölind & Lars M.H. Ulander
FOI Swedish Defense Research Agency
Linköping Sweden

***Abstract*—SAR interferometry, requires the sensor separation to be below a critical baseline above which the coherency is lost as the ground projected frequency ranges do not overlap (frequency band shifting of one sensor –the δ-k system– is not addressed here). Indeed, as critical baseline increases with both wavelength and bandwidth, low frequency and/or wide band SAR systems have less stringent constraint for interferometric coherence, which is especially worthy for airborne acquisitions. However, as mentioned in earlier publications, the number of fringes apparent on an interferogram is (roughly) limited to twice the inverse of the relative bandwidth. Hence, wide band interferometry requires range migration evaluating for maintaining coherency, this range migration evaluation is similar to a stereogrammetric measure. As relative bandwidth grows, the two techniques merge, which can be illustrated from FOI Carabas VHF SAR data (of which the relative bandwidth is 111%).**

Keywords-component; SAR interferometry; SAR stereogrammetry; wide band SAR; low frequency SAR

I. Introduction

SAR interferometry requires the two images to have intersecting spectral range (both in range and Doppler axes) for allowing coherent measurement on clutter areas. The common spectral domain is generally filtered on each image prior to their multiplication in order to increase signal to noise ratio on the interferogram. This requires the looking direction to the ground to be the same (it is called “Doppler matching” in spaceborne applications) and the difference of incidence angle (which yields the phase/elevation proportionality) being below a “critical baseline” angle.

The origin of this critical baseline angle is that bandwidth of the sensors when projected on the ground plane (or the local tangent plane to the ground) spans a range of spacial frequencies on the ground surface. Above the critical baseline angle, the two frequency ranges corresponding to both sensors incident angle do not match any more, hence there is no correlation on clutter (featureless) areas. Clearly from this origin, the critical baseline angle increases with relative bandwidth (the ratio between the bandwidth and the central frequency). Note it may be possible (if the sensor hardware is flexible enough) to override this limitation by offsetting the transmitted band of one of the sensors in order to have the ground-projected frequency ranges to match. This method (δ-k SAR system [1]) is not addressed here because it requires a good baseline forecast only available to spaceborne systems.

For airborne SAR, there is an extra difficulty in flying a plane several times on parallel flight lines. Reference [2] describes an S-band test with 70cm range resolution and the poor inertial trajectories available at ONERA in 1996. It illustrates the tedious trajectory estimation and adjustment and the consequences of a very irregular sensor separation along track. With present days highly accurate guidance and wider bandwidth, 10 cm resolution X-band repeat-pass

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interferometry becomes a common production [3].

Higher range resolution, however, have a geometrical drawback: Interferometry also requires the images to be matched geometrically, and an higher resolution means an higher absolute accuracy in matching. The problem is that the image matching depends on terrain elevation (it is the stereo effect) which is precisely what the interferometry is intended to retrieve. One way to quantify this effect is to consider what a phase turn (the so called elevation ambiguity) corresponds to: a range difference of half the wavelength. Since the range resolution is roughly the half the wavelength divided by the relative bandwidth (or the light velocity divided by twice the bandwidth), it is clear that the coherency vanishes as soon as the phase have made the inverse of the relative bandwidth turns. In simpler words the number of fringes an interferogram (without non homogeneous range migration) may have is limited to twice the inverse of the relative bandwidth.

II. Range Migrated Interograms

The obvious solution for this difficulty is to distort one of the image (the slave one) along range in order to keep the interferogram coherent. This migration being made phase-preserving (which requires a little care) we can achieve interferogram with an arbitrary number of fringes.

The estimation of the local range migration can be done by several means such as amplitude sub-image correlation, complex sub-image coherency maximization, and (for fine tuning the range difference) local range-Fourier transform interferogram slope estimation. References [4] and [1] quantify the accuracy of this process in the relatively low signal to noise ratio characterizing spaceborne SAR systems. In our airborne case, the signal to noise ratio is very high, allowing routinely a range matching with an accuracy of 1/16th of the range resolution on clutter (speckle only) areas. The reason is that speckle self-correlation has a peak with the aspect of the square of the SAR pulse response, and in high signal to noise conditions it is easy to estimate the peak position at a fraction of its 6 dB width.

Furthermore, the range migration itself provides an information that is relevant to the phase unwrapping. At the limit, with increasing relative bandwidths, the range migration accuracy and the baseline angle could increase to the point the stereogrammetry (the use of the range migration to retrieve terrain elevation) and the interferometry (the use of unwrapped phase to retrieve terrain elevation) technique merge.

III. Illustration with Carabas SAR images

High resolution X or Ku-band images available at ONERA was only enough to give an insight of this merging of the two techniques as the relative bandwidth is about 12%.

Common FOI-ONERA campaign in 2004 gave us an occasion to test this on the VHF Carabas images of which the relative bandwidth is about 111% (range 3 dB resolution is around 2.25 m). Repeat-pass interferometry have been already demonstrated on this system [5] [6], and the campaign produced pairs of images with incidence difference of 18° (3.5 km baseline) that promised a good efficiency of the stereogrammetry approach. Due to the high relative bandwidth, this baseline was below the critical one, allowing us to compute interferograms with 10 m ambiguity elevation.

Figure 1 shows the same SAR image pair processed as an interferogram (with phase color coded on the amplitude image) and processed with stereogrammetric approach (in fact a by-product of our interferogram producing software) with range migration estimate color coded on the amplitude image.

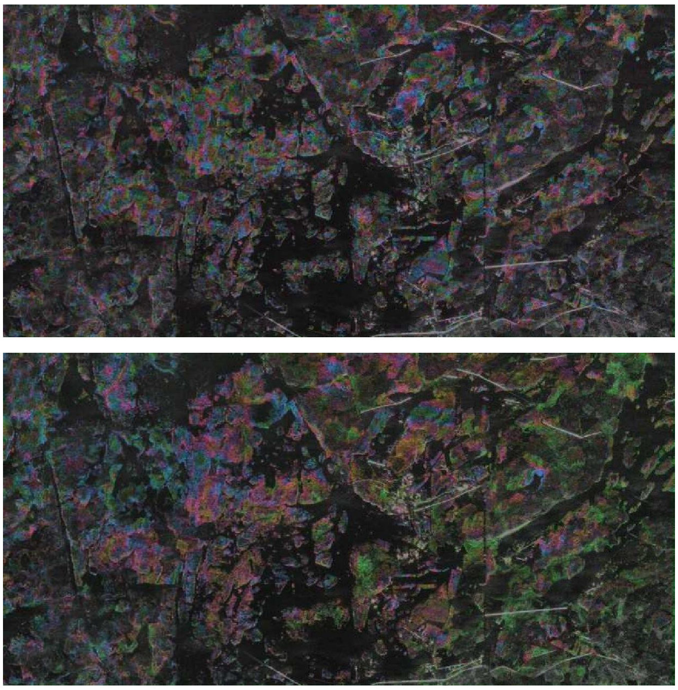

Figure 1. Comparison of the interferogram (top) and a stereogrammetric range migration (bottom) for the same pair of VHF SAR images. Relative bandwidth is 111%, baseline 3.5 km (18° angle). Range resolution is 2.25 m, ambiguous height 10 m.

References

[1] R. Balmer and M. Eineder, "Accuracy of differential shift estimation by correlation and split bandwidth interferometry for wideband and δ-k SAR systems" IEEE Geosc. Remote Sensing Letters, vol 2, pp 151-155, 2005

[2] H. Cantalloube and C. Nahum, "Repeat-pass airborne SAR interferometry" proc. EUSAR München (Germany) 2000.

[3] X. Dupuis et al. "Very high resolution interferogram acquisition campaign and processing" proc IGARSS, Barcelonne (Spain) 2007

[4] R. Balmer, "Interferometric stereo radargrammetry: Absolute height determination from ERS-ENVISAT interferograms" proc. IGARSS, Honolulu, 2000

[5] L. Ulander and P.O. Frölind, "Ultra-wideband SAR interferometry" IEEE trans. Geosci. Remote Sensing, vol 36, pp 1540-1550, 1998

[6] P.O. Frölind and L. Ulander, "Digital elevation map generation using VHF-band SAR in forested areas" IEEE trans. Geosci. Remote Sensing, vol 40-8, pp 1769-1776 2002