Single Antenna Interferometry

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Abstract

Interferometry from air and space borne platforms which require synthetic aperture radar image synthesis has been demonstrated in earlier experiments by using either two physical antennas mounted on one airframe or two passes of the same antenna over the same scene. In this paper, one pass of a single antenna radar system with a high pulse repetition frequency is used to form an interferometric image which, under initial investigation, appears to be sensitive to ocean surface effects due to ship-generated internal waves.

Discussion

The NASA/JPL airborne radar laboratory (also known as AirSAR), has a multifrequency (P, L, and C bands), multipolarization (full quad), synthetic aperture radar (SAR) capability. Because there are L and C band antennas mounted both fore and aft on the DC-8 and a common coherent reference is used for mixing to the intermediate frequency (IF), interferometric SAR at these wavelengths is also possible. The concept of using interferometric SAR for extracting topographic information (pixel-height) has been discussed in the open literature (see [2] and [3]). In addition, Li and Goldstein [4], have demonstrated with Seasat data that interferometry can be performed using two overlapping swaths obtained during separate orbits. The interferometric images produced in these imaging geometries have been visually spectacular.

The proposed Single Antenna Interferometry (SAI), technique differs from earlier approaches because it expolits the high pulse repetition frequencies (PRFs) associated with most airborne SAR systems to collect the required data in one pass with one antenna. The standard SAR data collection geometry is used for gathering the data required for the single antenna interferometer (see Figure 1). The size of the footprint is $\lambda R/D$, where λ is the radar wavelength, R is the range from antenna to the scattering area, and D is the along-track dimension of the antenna. The forward motion of the aircraft is used to sequentially illuminate a swath on the ground where the radar footprints from each echo overlap extensively. The Doppler frequency coding in a series of overlapping measurements is used to focus a synthetic antenna in the along-track direction [5].

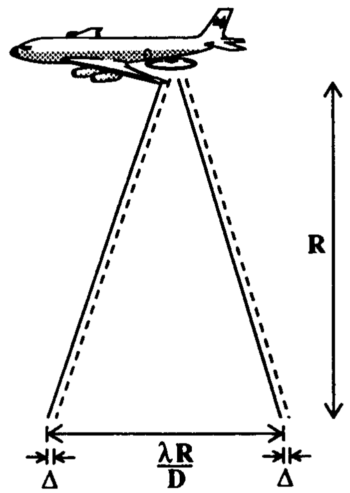

Figure 1: Data collection geometry for single antenna interferometric synthethic aperture radar.

Because the radar system and the SAR image synthesis use coherent processing, the SAR output can be generated as a complex-valued image (in-phase and quadrature). If the complex-valued SAR image is treated as a wavefront, then interferometry can be accomplished when a suitable reference wavefront can be provided for mixing. The reference wavefront is suitable if it is of the same scene as the original SAR image and within the coherence time (distance) of the system. For the multi-pass Seasat work [4], the ground-patch of interest was selected because it was not expected to have changed dramatically during the time between passes. For radar ocean imaging applications the scene decorrelation times are relatively fast and obviously depend on radar wavelength. The two-antenna interferometric configuration on the NASA/JPL AirSAR has already demonstrated impressive imaging capabilities for ship-generated wakes at L-band.

The input to the single antenna interferometer (SAI) is two complex-valued wavefronts obtained by decimating the original radar echoes into two sets for separate processing (one set is from even-indexed echoes and the other set is from odd-indexed echoes). A standard SAR image is formed from each of these sets but now the inter-sample spacing has doubled and the pulse repetition frequency is half of the original system. However, un-aliased images can still be formed if the original PRF is at least twice the Nyquist rate. The two images are registered, one of the images is complex-conjugated, the images are beaten together on a pixel-by-pixel basis, and the phase is stripped from the resulting product. The data flow for the processing is outlined in Figure 2.

For SAI-SAR, the registration operation corresponds to shifting one of the two images half a pixel. The current implementation uses a spatial domain filter for interpolation; the truncated (4-point) sinc appears to work well. Alternatively, the shift could be implemented in the frequency domain as a phase weighting of $exp(-i2\pi f_x \sigma/2)$. Combinining this with the standard SAR azimuth focusing reference [5], generates a

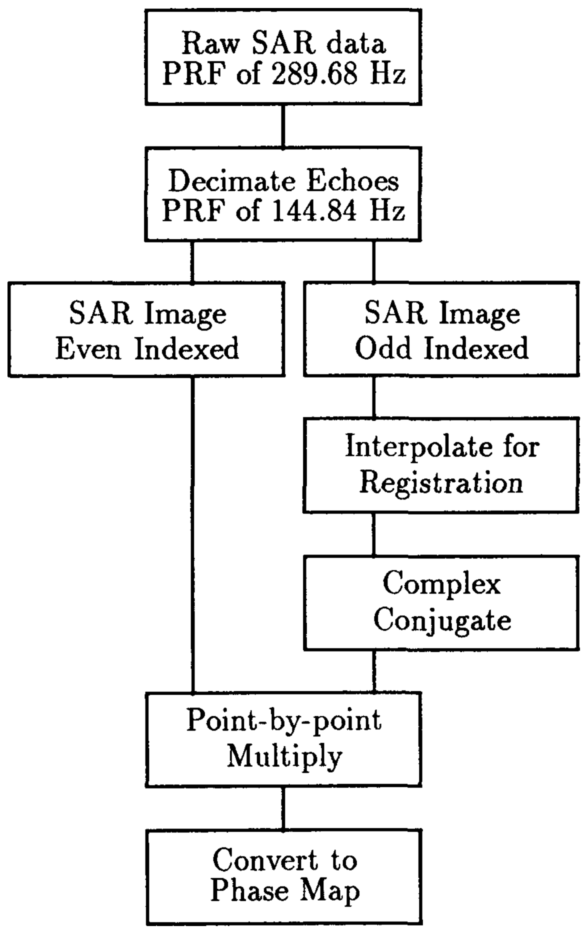

Figure 2: Data flow for the single antenna interferometric synthethic aperture radar processing.

single compression filter of the form

$$e^{-i2\pi f_x \sigma/2} \quad e^{-i2\pi(f_d t + 0.5 f_r t^2)} \tag{1}$$

where f_d and f_r are the Doppler frequency centroid and Doppler rate, respectively. From Equation 1 it is clear that interpolation is equivalent to changing the Doppler centroid f_d–*i.e.*, squinting the synthetic beam.

Results and Preliminary Analysis

Figure 3 displays two images: on the left is the phase output of the interferometer with a set of fringes running across the center of the image, on the right is one of the two SAR images used in the interferometry (this image is magnitude detected). Figure 4 has the standard SAR output which is not decimated and has the highest resolution of the three images. These images are at L-band ($\lambda = 24cm$) and were taken on August 27 at the Loch Linnhe 1989 experiment.

In order to discuss why it is possible to see a phase contour co-located with the ship wake, a quick review of the correlation between radar pulses is required. Suppose that the along-track dimension of the ground patch illuminated by a real aperture radar (RAR) is ρ. For the antenna system shown in Figure 1: $\rho = \lambda R/D$. After SAR processing using the maximum allowable synthetic aperture the resolution is $\rho = D/2$. Assume for the moment that the system is a RAR, then for a scattering response of s, the received signal is given by

$$r_0 = \int_0^{\rho} s(x)\, dx. \tag{2}$$

When the antenna platform has moved a distance Δ, the received signal becomes

$$r_\Delta = \int_\Delta^{\rho+\Delta} s(x)\, dx. \tag{3}$$

For a scattering response with a Dirac-delta autocorrelation, the correlation of the received signal becomes

$$A_\rho(\Delta) = E\left(r_0^* \quad r_\Delta\right) \tag{4}$$

$$= \int_0^{\rho} \int_\Delta^{\rho+\Delta} s^*(x_0)\, s(x_1)\, dx_0\, dx_1 \tag{5}$$

$$= \begin{cases} \rho - |\Delta| & \text{if } 0 \le |\Delta| \le \rho \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

In simple terms, two received signals must be uncorrelated if there is no overlap in their footprints. It is tempting to immediately conclude that the along-track echo spacing for a SAR system must be less than $D/2$ in order for the two SAR images in the interferometer to be mixed together and produce fringes. Recall that the $D/2$ is applicable only if the full synthetic aperture is used to process the imagery. Smaller synthetic apertures can be used in the processing which admit larger resolutions ρ

and consequently better correlation and stronger fringes. Interpretations from optical interferometry are tempting: by reducing the bandwidth (in this case Doppler bandwidth), stronger fringes are possible. The SAI acts like a beam-splitter followed by superposition of the two beams after different propagation paths have been followed: smaller bandwidths increase the correlation time (length) of the radiation.

The Doppler frequency is twice the target-antenna velocity divided by the wavelength. As the target moves further from broadside of the antenna platform, the Doppler frequency magnitude increases. Some of the important processing and physical parameters for the attached imagery is included in the following table.

0.239	meters	Wavelength (L-band)
289.68	Hz	Pulse Repetition Frequency (PRF)
219.	meters/sec	True Ground Speed
0.756	meters	Azimuth sample spacing
11970.	meters	Near Slant Range
50.52	Degrees	Approximate Incidence Angle
8.0	Degrees	Azimuth 3dB Beamwidth
4.0	Degrees	Size of Synthetic Aperture Processed

Conclusions

In this paper a single radar antenna with a high pulse repetition frequency and a single pass of the scene is used to form an interferometric image which, under initial investigation, appears to be sensitive to ship-generated wakes. Additional applications including velocity estimation and topographic mapping from air and space borne platforms are being considered. Using the SAI to interatively correct for Doppler parameter errors is also being implemented.

Acknowledgements

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References

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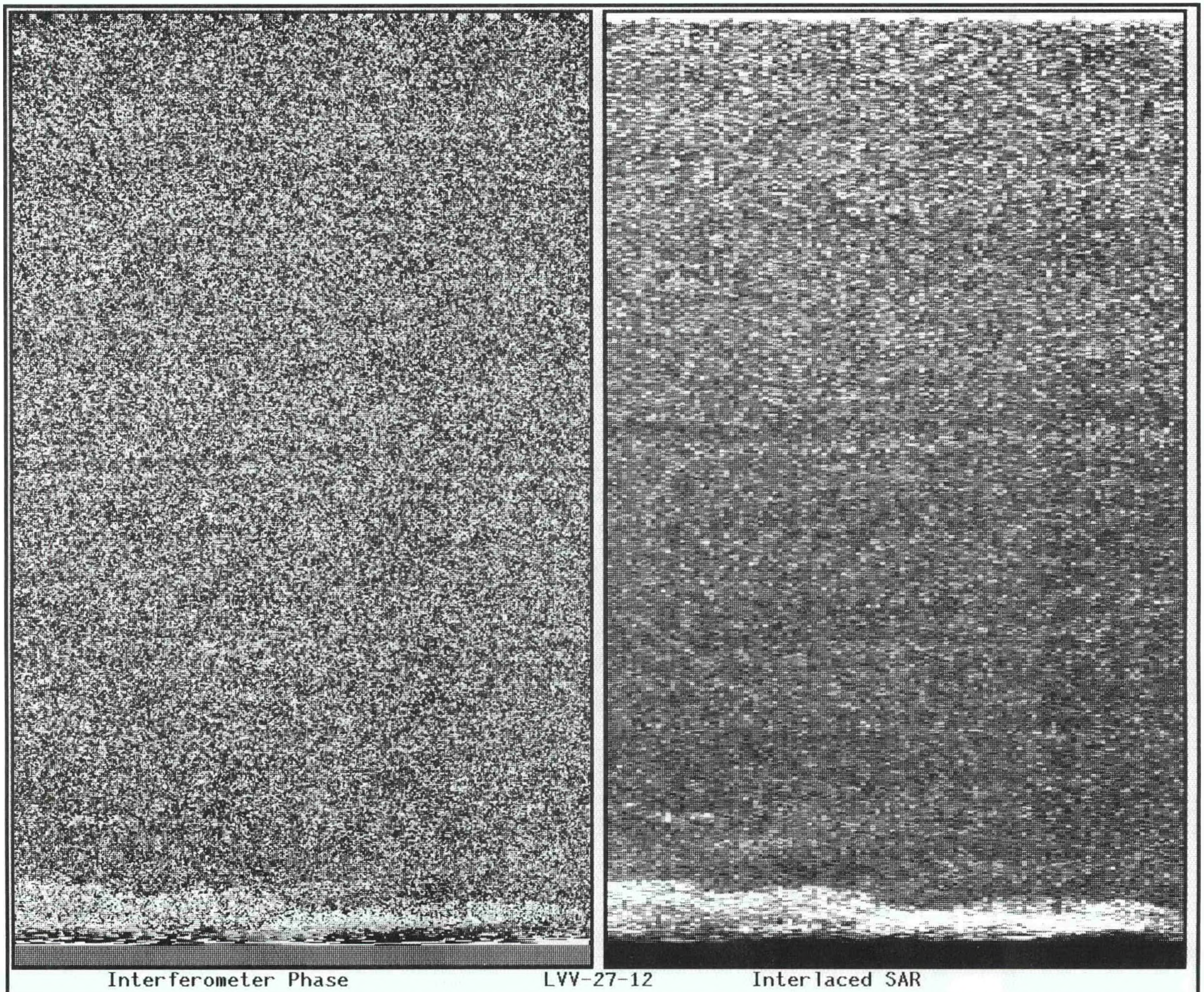
Interferometer Phase
LVV-27-12
Interlaced SAR

Standard SAR: LVV-27-12

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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TECHNICAL SUPPORT PACKAGE

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Multiple-Baseline Interferometric Synthetic-Aperture Radar

Performances of spaceborne systems and effects of phase errors are discussed.

A report discusses the performances of spaceborne interferometric synthetic-aperture radar (SAR) systems in terms of the utility of SAR echo data in the generation of topographic maps. In the interferometric SAR (INSAR) approach, conventional digital SAR echo data taken along nearly-repeat ground tracks are combined coherently to synthesize interferometric SAR data. The resulting interferograms yield data on the height of the terrain in each picture element.

Airborne INSAR has already been shown to yield maps comparable with conventional topographic contour maps. The purpose of the report is to demonstrate the potential utility of INSAR in a spaceborne setting to obtain global coverage. To illustrate the concept, the report uses a set of SEASAT data on the Cottonball Basin of Death Valley, taken from five orbits that were close enough to each other so that adjacent ones approximated the two-antenna configurations of airborne SAR. The Cottonball Basin was chosen because it is dry and, therefore, was not expected to change significantly during the 3-week interval that contained the nearly repeating orbits. (Any change would increase phase noise.)

The report discusses the processing of the raw SEASAT data, including such problems as the registration of the separate complex-amplitude SAR images. The accuracy of the resulting topographical measurements is assessed.

Particular attention is given to phase-measurement errors, a mathematical model of which is described. The model has important implications for the design of future spaceborne INSAR. It shows among other things that, although the sensitivity in the measurement of altitude increases with the baseline separation, so does the phase error. Indeed, there appears to be an optimal baseline separation that balances these two opposing factors. The model is compared with interferograms synthesized from the data obtained at the various baseline separations (between orbits), and it is found to agree qualitatively with the interferometric data.

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