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An Interferometric Quick-Look Processor

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Abstract

A real time technique to get strip-map SAR interferograms and coherence maps with common Unix Workstations / PC is presented. For the ERS mission, the ``real time'' throughput corresponds to approximately 1/8 of PRF: e.g. approximately 3 min for processing a 100 x 100 km image pair. The proposed algorithm computes a multi-look averaged interferogram + coherence map (at a resolution 50 x 50 m) in 18 minutes by means of a low cost PC (Pentium Pro). This goal is achieved, at a price of some data loss, by exploiting fast techniques for presumming, focusing, image coregistration and coherence estimate.

Introduction

With the huge amount of interferometric SAR data that are now and potentially will be available from satellite SAR missions (ERS-1, ERS-2, RADARSAT, SIR-C/X-SAR III), the computing time to obtain interferograms and coherence maps in a semi-operative scenario should be kept as short as possible. Thus, to select SAR pairs that actually can be exploited for interferometric applications the generation of fast, low-resolution surveys (e.g. fringes and coherence maps) should be carried out routinely on those pairs that show a suitable perpendicular baseline.

A ``quick-look`` processor is presented in this paper. The processor computes *interferogram and coherence maps* in blocks of 33 x 100 km, at a geometric resolution *45* x *45 m* on the ground (for flat earth). A good altimetric accuracy has been achieved by averaging the interferograms of *5 azimuth looks*. Several adjacent ``blocks`` are then mosaicked to get a continuous azimuth strip.

The processor performs near to real time on common low-cost machine: approximately *6 min* are requested to compute a single block (*32 x 100 km*, 5 looks averaged) interferogram & coherence map, by using a *PC PENTIUM PRO 200* running under Unix. Real time processing, i.e. 8 x the survey time (including some margin for data ingestion from HDDT), would require a machine 5 times faster.

Efficiency has been obtained, at a cost of some quality loss, by designing fast techniques for:

- range and azimuth focusing,
- images co-registration,
- estimate of coherence maps.

Raw data presumming

The look formation is performed, before range and azimuth focusing, by bandpass filtering and subsampling raw data. This approach gives the following advantages:

(a)
the data rate is reduced by discarding less correlated (and noisy) contributions both in azimuth and in range. For range presumming, the central frequency is tuned according to the spectral shift predicted by the baseline [1].

(b)
2D wave-number domain focusing can be performed on smaller kernels and with ``approximate'' references. These kernels fit better in the processor cache. Moreover the cost of the Fourier Transforms is reduced.

(c)
The processor can be easily implemented on multi-processor machines.

The cost of presumming stage is minimized by using polyphase filters and implementing an ``integer'' format that handles one complex (I+Q) sample as a single integer word (16 bits) [2].

The processing time is thus reduced by a factor of 2.2 times due to range presumming (half band is dropped), 2 times due azimuth presumming (3 of the possible 8 looks are discarded) and 1.3 due to approximate focusing. These improvements are achieved at the cost of some information loss: nominally 50 % of the signal (for very low baselines) is lost due to range presumming and almost nothing for azimuth baseline in the tandem case due to the 300 Hz Doppler shift.

Coherence estimate

A *fast algorithm* has been designed *(*named *quick & dirty)* to compute coherence maps. The estimator achieves a computational time gain greater than 100, with respect of the conventional estimator, at the cost of a reduced statistical confidence (its accuracy being 3 to 5 times worse for coherence values > 0.4).

The proposed estimator exploits the images amplitudes, and it is based upon the relation between the absolute value of the complex coherence,

$$\gamma = \frac{\left|E\left[v_1 \cdot v_2^* \exp(j\phi(x,y))\right]\right|}{\sqrt{E\left[|v_1|^2\right] E\left[|v_2|^2\right]}}$$

(being $\phi(x,y)$ the averaged interferometric phase), and the normalized cross-correlation *r* of the detected SAR images:

$$r = \frac{E\left[(|v_1|^2) \cdot (|v_2|^2)\right]}{\sqrt{E\left[|v_1|^4\right] E\left[|v_2|^4\right]}}$$

The following expression [3]

$$r = \frac{\gamma^2 + 1}{2}$$

can be exploited to compute the complex coherence, given an estimate of the normalized cross-correlation of the amplitude image, *r*. The amplitude based coherence estimator is more efficient, since it does not require the knowledge of the interferometric phase (or local frequency). Moreover, it is not affected by possible local frequency estimation errors being insensitive to the interferometric phase.

It can be shown that the proposed estimator is strongly biased by amplitude non stationarities, however this bias can be effectively reduced by applying a sort of automatic gain control (AGC) to both detected images before computing the coherence estimate [3].

The proposed estimator can be efficiently implemented to compute a coherence map by exploiting overlapped Bartlett or Boxcar windows at a cost of 50 flops for each image pixel, independently of the window size.

Image coregistering & oversampling

The estimate of co-registering parameters has been improved by means of the ``*quick & dirty*'' coherence estimator. Large windows can be explored since the estimator is independent of fringes & phases non-stationarities. Image co-registration is performed by two 1D resampling, since, for ERS, image rotation is well approximated by means of two 1-D skews.

Short space domain kernels are used for resampling & oversampling at the same time. Kernels are optimized for minimal phase noise and tabulated in steps of 1/100 pixel. A 6-7 samples kernel gives a coherence loss less than 2%. This approach is faster than frequency domain processing.

Interferogram generation

The looks image are aligned in phase (to recover the effect of approximate resampling) and then coherently averaged. The multiple look interferogram is performed as usual by conjugate cross-multiplication. Finally the low-resolution interferogram (fringes) is generated by filtering and subsampling. Here again short kernels (6 samples) are used. After mosaicking the blocks to get a large strip, a residual range flattening is given to compensate for flat earth. Notice that these steps are not requested if the generation of coherence maps is the sole requirement.

Computational complexity

The computing time achieved by the interferometric quick-look (for a 33 x 100 Km image block) is summarized in table 1.

Processing Step

Doppler Centroid Estimate

TOTAL

Coherence Estimate

	Quick-look			**Polimi-ESA**
	CPU time [min:sec] 1 look	5 looks	Mflops	CPU Time [min:sec]
0:01	0:01	-		
Baseline Estimation	0:01	0:01	-	
Filtering and Subsampling	*1:10*	*1:10*	31	
Focusing	*0:36*	*3:00*	27	
Registration params. estimate	0:03	0:03	-	0:30 - 15:00
Image #1 Resampling	*0:20*	*1:40*	27	0:41
Image #2 Oversampling	*0:05*	*0:25*	30	0:11
Interferogram Generation	0:06	0:07	31	
2:22	6:27			
0:14	*0:30*		48:28	

Table 1: Computing times (first two columns) and computational complexity (third column) for getting a 33 x 100 km interferogram and coherence map by means of the proposed quick-look processor. Last column: computing time requested to process the same amount of data with the standard processor (POLIMI-ESA). Time measures have been made by means of a 30 Mflops/s Unix Workstation, e.g. equivalent to a PENTIUM PRO 200.

The most time-consuming steps have been highlighted in italics. Note the advantage achieved with respect to the standard - public domain interferometric processor, due to a much more efficient way to compute coherence.

Conclusions

An algorithm for generating interferograms & coherence strips has been presented. It is intended for data screening / browsing. All the processing steps requested for generating the interferogram have been revisited - efficiency has been achieved by keeping coherence loss due to processing less then 5%. A ``*quick-and-dirty*'', phase-independent coherence estimator has been introduced. It requires 14'' to compute a 33 x 100 km, 5 looks averaged coherence map.

A 5 looks averaged, 33 x 100 km ERS interferogram can be computed in 6' with a 30 Mflops/s Workstation. A prototype processor, installed at ESRIN, has produced several interferograms and coherence strip-maps more than thousand km long.

Acknowledgments

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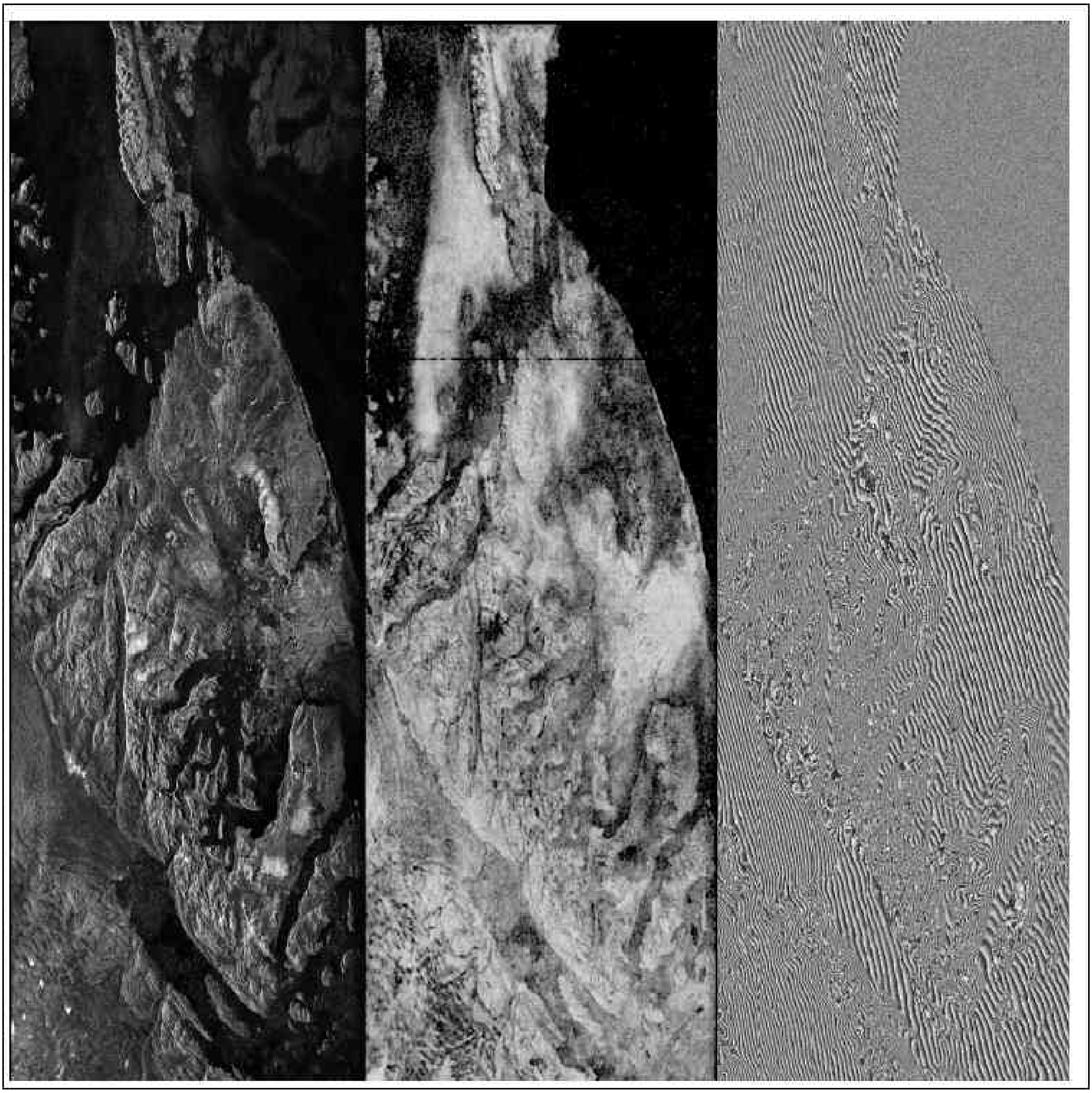

Figure 1: Low resolution interferogram from ERS-1/ERS-2 tandem mission (jan '96), Greenland. Images' size is approximately 300 x 100 km. Left: absolute value; center: coherence map; and right: fringes.

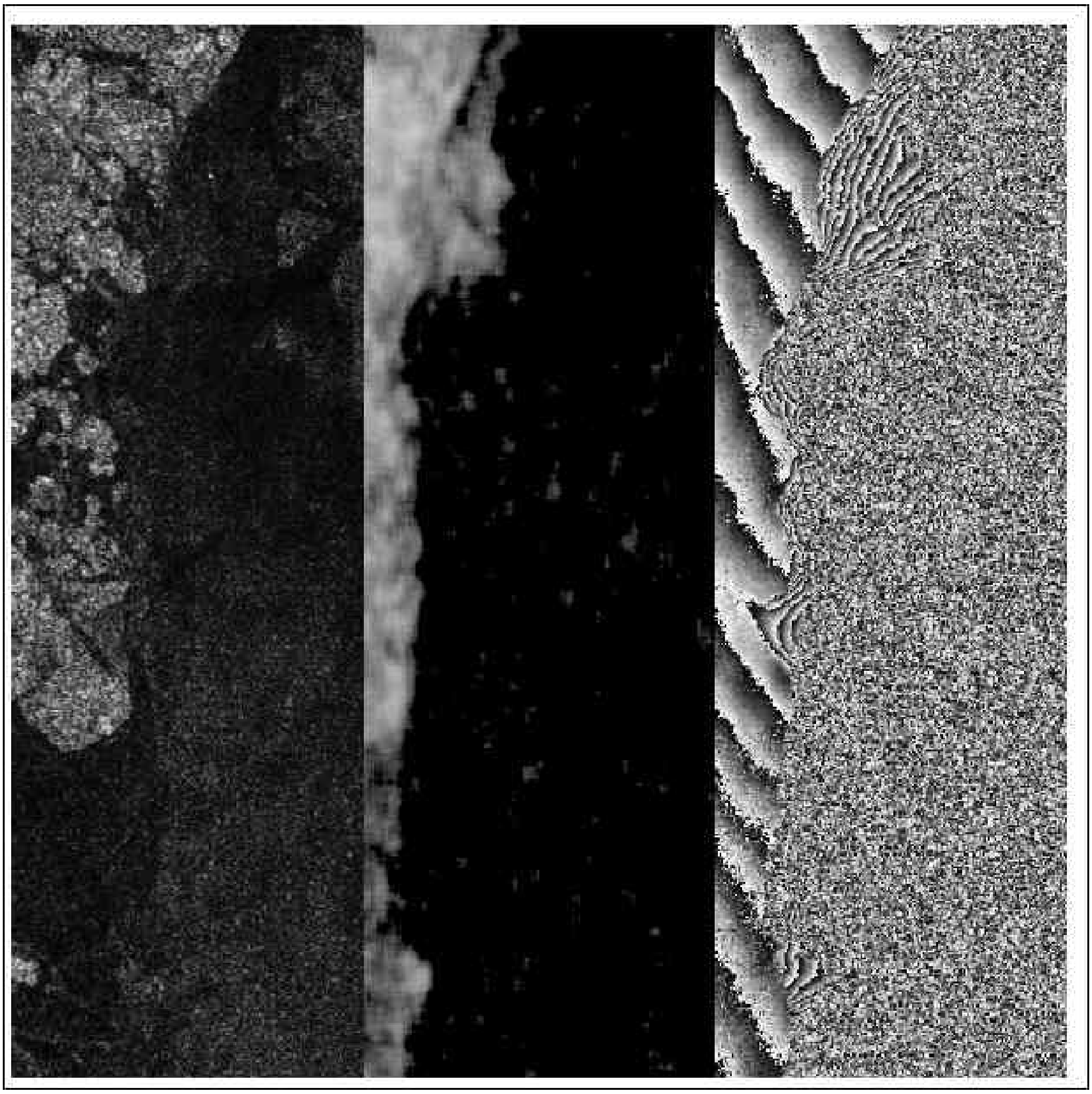

Figure 2: Enlargement of the previous image: an area of approximately 7 x 15 km has been shown. Note the fast fringes due to the movement of ice near the coast (iceberg ?).

References

1
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4
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