

Applications of Time-Domain Back-Projection SAR Processing in the Airborne Case

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Abstract

The Back-Projection Algorithm is a SAR processing approach that uses time-domain convolution of the SAR data in order to perform SAR focusing. Some benefits of this approach are exact inversion, ideal motion compensation including topography information and handling of general aperture geometries. The implementation of the Back-Projection Algorithm was done focusing on the parallelization aspects. Applications of the algorithm are presented with respect to topography adaptive processing, direct generation of map projections and consideration of non linear trajectories.

1 Introduction

1.1 SAR Processing Algorithms

Several SAR processing algorithms have been proposed in the literature, mainly divided in two broad classes: FFT-based and time domain processors, each one having its benefits and disadvantages. FFT methods are known for their efficiency but have limitations, mainly due to their specific assumptions [1]. Range-Doppler and Chirp-Scaling rely on approximations that break down for large apertures and Doppler centroids. The ω -k algorithm is geometrically exact, but it assumes a perfectly straight trajectory. Deviations from a linear uniform trajectory are a bottleneck for these algorithms in an airborne scenario. To compute along-track FFTs, a full aperture of pulses must be acquired and so the processing is performed in blocks. Topography- and Aperture-Dependent (TAD) motion compensation algorithms based on block processing have been developed to overcome this limitation [2].

The time-domain back-projection approach performs processing on a pulse-by-pulse, pixel-by-pixel basis, being able to perform ideal topography-dependent motion compensation. Also, due to this characteristic, back-projection algorithms are more easily implemented in parallel processing architectures. The drawback of the back-projection approach to SAR processing is its computational load. Fast back-projection methods [3][4] have been developed to overcome this deficiency. In this work, the direct back-projection approach is parallelized to improve the computation efficiency. Further gain in processing speed can be obtained by only processing areas of interest.

1.2 The Back-Projection Algorithm

The back-projection algorithm works interpolating each received echo at the desired positions to be focused at the pulse's illuminated area on the ground. Given that the radar echo has been sampled according to the Nyquist criterion, the radar echo can be interpolated with arbitrary accuracy at any illuminated image position. By coherently adding the contribution of each echo to each desired position, focusing is performed.

Due to this pulse-by-pulse, pixel-by-pixel approach, back-projection algorithms are suited for general geometry platform tracks, as well as processing in coordinates other than slant-range azimuth, e.g., processing directly in UTM (Universal Transverse Mercator) geocoded coordinates.

Section 2 describes how the algorithm was implemented. Section 3 presents results comparing processing assuming a reference height and using a DEM for topography-dependent motion compensation. Section 4 presents results of an experiment on a non linear SAR geometry acquisition.

2 Implementation

The back-projection algorithm was implemented in IDL and C languages. Chirp signal range compression and FFT-based presumming stages were included. Given the low-pass characteristics of the presumming stage, first order Motion Compensation is performed before presumming, taking midrange as a reference.

In the back-projection kernel loop, each pulse is up-sampled and interpolated at distances correspondent to slant-range azimuth positions or a chosen ground UTM coordinate grid. Such a direct processing of selected geocoded areas is particularly suitable for scenarios where only a part of the image is of interest, e.g., the monitoring of roads. As the processing steps are performed only for the selected area, the computational burden is greatly reduced when compared to the processing of the whole image.

In C language, the back-projection kernel loop was implemented supporting thread parallelized processing. In multiprocessor architectures, parallelized processing reduces greatly the computational time of the back-projection loop, by a factor almost equal to the number of processors used.

Motion compensation is performed when calculating the distances between platform and the desired positions in the output grid, with which the pulses are interpolated. When available, an external Digital Elevation Model (DEM) can be utilized to correctly account for topography while calculating these distances, hence performing accurate topography- and aperture- dependent motion compensation.

3 Experimental Results

3.1 Topography-Dependent Motion Compensation

An X-Band single-pass interferometric data set, acquired at the Swiss Alps by the DLR's E-SAR system in 2006, was chosen to test the topography-dependent motion compensation performed by the algorithm.

Figure 1 shows a piece of the processed channel 1 data (in slant-range azimuth coordinates). Near range is at the left side of the image. It is possible to recognize mountains at the left superior corner and a more smooth area at the right inferior sector. The dark areas correspond to shadowed regions.

Figure 2 shows the interferogram of the processed master and slave images, using the back-projection algorithm and a DEM to account for topography.

Figure 3 shows the difference between interferograms of master and slave images processed assuming a constant reference height and master and slave images processed taking topography in consideration. Although in single-pass systems the errors due to the assumption of a constant reference height tend to cancel out due to the correlation of master and slave track deviations, in areas with strong topography the error can reach critical values, as shown in Figure 3. It is possible to notice considerable difference in the left superior corner of the image, where the topography is indeed stronger.

To illustrate the speed gained when a parallelized processing architecture is used, a graphic of the duration of the back-projection loop, having processed a particular section of this scene, versus the number of

parallelized processors used is displayed in Figure 4. As commented before, it can be noted how the processing time is reduced by a factor equal to the number of processors.

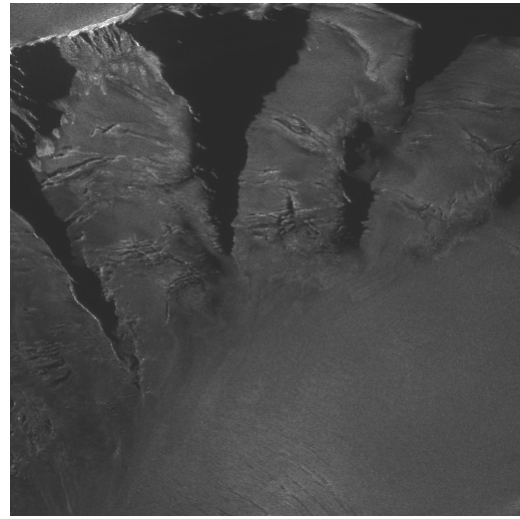


Figure 1 Processed Image.

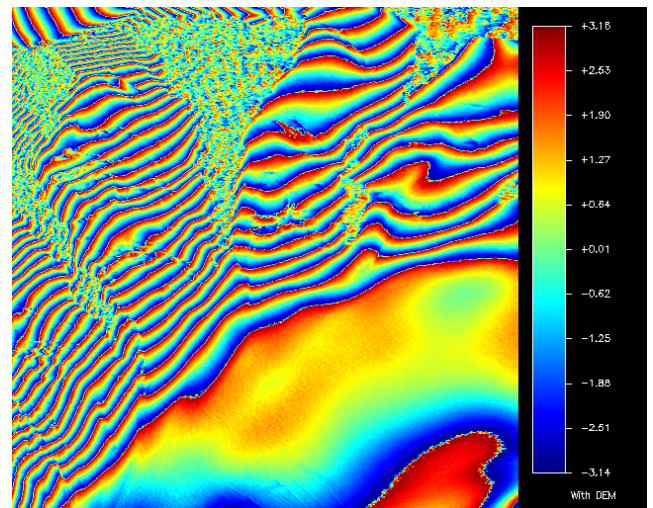


Figure 2 Interferogram using DEM.

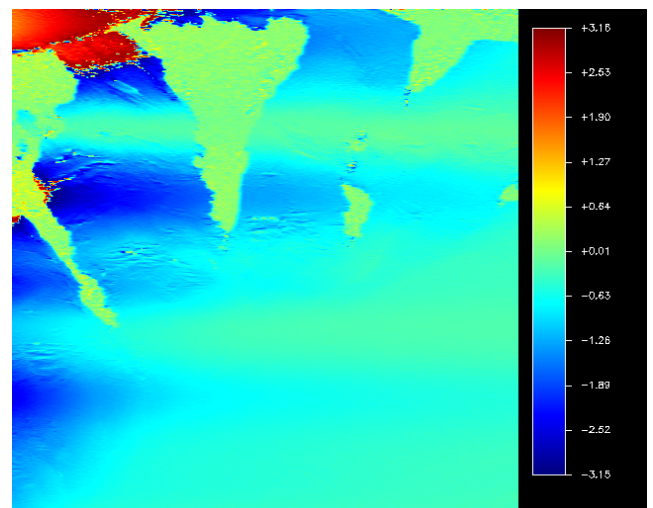


Figure 3 Difference between Interferograms.

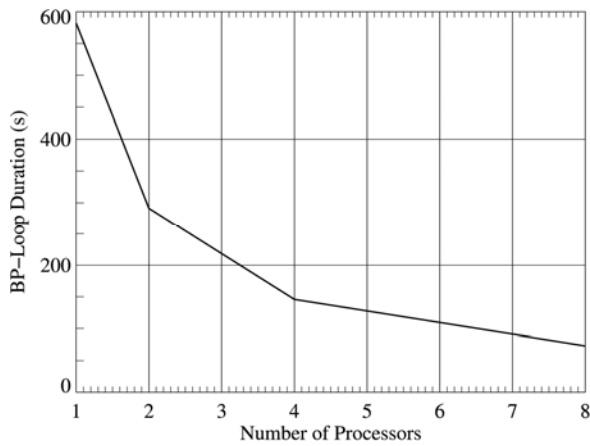


Figure 4 Parallelized processing.

3.2 Circular Spotlight Experiment

A circular flight experiment was performed by DLR's E-SAR system in October, 2006 at Emmen, CH. Due to the large deviations of the flight from a rectilinear trajectory, the processing of the data with frequency-domain methods did not result in a properly focused image.

The flight corresponded approximately to a 60° arc of a 5200 m radius circumference, at an altitude above ground of 2920 m. Using GPS and IMU (inertial motion unit) data, the flight trajectory was parameterized in coordinates according to axes which would provide best linear fit.

The area chosen for processing is such that it is illuminated by the radar during the entire flight trajectory. It is a square of 800 m by 800 m. A constant height was assumed and a pixel spacing of 0.2 m was arbitrarily chosen for the output grid in both axes.

The pulses acquired in the flight were divided in 60 groups corresponding approximately to 1° arc of circumference. These were processed separately and added together afterwards when convenient.

Figures 7 to 11 show some of the reflectivity images obtained, as well as an optical image taken from Google Maps as a visual reference.

It is possible to notice reduction in image speckle as larger angle apertures are assembled. It is also interesting to notice how some targets appear only when observed from particular angles. A clear example of that are the power lines at the lower half of the image. Observed from the left, only the right part is visible, the opposite happening when observing from the right. It is also possible to observe clear differences at the images shadows with respect to direction and, as larger apertures are assembled, to size.

A RGB image, composed by the first 30° subaperture,

the last 30° subaperture and the sum of both is presented in Figure 10. At the up left and right corners of the image, stronger red and blue tonalities are no-



Figure 5 Optical Image.



Figure 6 1° Subaperture.



Figure 7 First 30° subaperture.



Figure 8 Last 30° subaperture.



Figure 9 60° Aperture.

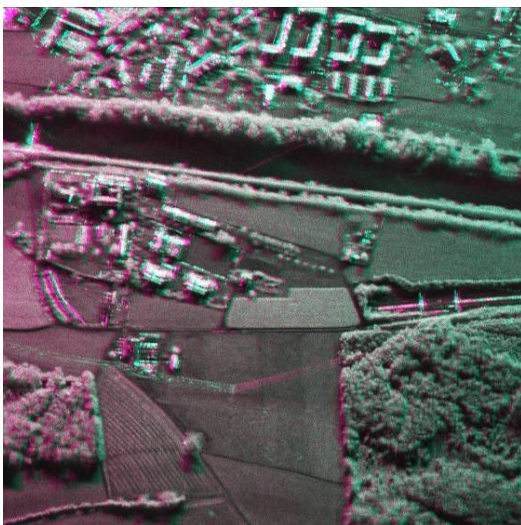


Figure 10 RGB Image.

ticeable, respectively. This can be accounted for by the antenna pattern, which does not illuminate the area with the same intensity for all pulse acquisitions.

Important aspects limiting image improvement processing larger angle apertures are reflectivity changes in aspect and elevation angles observed by real targets and coregistration errors between the assembled subapertures. Although the subapertures are processed using an output grid that shares a common coordinate system, coregistration errors arise due to the assumption of a constant terrain height. This second source of error can be exemplified in the image at the road present close to the center left border of the image, which gets clearly blurred in the 60° aperture image. An available DEM of the area included during processing would greatly diminish this effect.

4 Conclusion

The back-projection approach is known to overcome most of the limitations of FFT based methods, at the expense of substantially greater processing time. With the fast increase of the speed of computer processors, this drawback becomes gradually less of a problem. Back-projection algorithms are considered as precise reference during the development of more efficient approaches, often being the only viable approach.

The use of non-linear geometries for SAR acquisitions presents promising performance in terms of resolution and, particularly to the circular aperture geometry, observability of a target's reflectivity for different aspect angles, beside being theoretically capable of tomographic imaging [5].

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References

- [1] Cumming, I.G.; Wong, F.H.: Digital Processing of Synthetic Aperture Radar Data. Artech House, 2005
- [2] Prats, P.; de Macedo, K.A.C.; Reigber, A.; Scheiber, R.; Mallorqui, J.J.: Comparison of Topography- and Aperture- Dependent Motion Compensation Algorithms for Airborne SAR. In *Geoscience and Remote Sensing Letters*, vol. 4 no.3, July 2007
- [3] Yegulalp, A.: Fast Backprojection Algorithm for Synthetic Aperture Radar. In *Proceedings 1999 IEEE Radar Conference*, Waltham, MA
- [4] Ulander, L.; Hellsten, H.; Stenström, G.: Synthetic-Aperture Radar Processing Using Fast Factorized Back-Projection. In *IEEE Transactions on Aerospace and Electronic Systems*, July 2003
- [5] Ishimaru, A.; Chan, T.; Kuga, Y.: An Imaging Technique Using Confocal Circular Synthetic Aperture Radar. In *IEEE Transactions on Geoscience and Remote Sensing*, September 1998