Development of a Multiple Adjustment Processor for generation of DEMs over large areas using SAR data

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Abstract— **During the last years orbital SAR data have been acquired for almost every place in the world. This fact can be used for generating large Digital Elevation Models (DEM) of remote areas using SAR Interferometry (InSAR). Nevertheless, the generation of large quality DEMs using this technique presents several problems, such as temporal decorrelation -even with a one-day temporal gap between acquisitions-, baseline errors or SAR parameters calibration. These factors can dramatically degrade the quality of the final DEM and, therefore, advanced InSAR techniques are needed to minimize or compensate for these errors. In this paper the Institut Cartogràfic de Catalunya (ICC) presents a robust method for generating very large, high quality DEMs using a set of SAR interferograms. The method is based on a simultaneous multiple adjustment of critical parameters for the SAR images using three types of phase-registered points: control points, known-height and corresponding points. Results for the area of Tierra del Fuego (Argentina) are also presented.**

Keywords— SAR, Interferometry, DEM

I. Introduction

One of the advantages of satellite SAR Interferometry is the capability of having a large set of data over nearly every place on Earth. This is the case for the ERS database, where combinations of ascending and descending interferometric frames are easily found. This characteristic makes this kind of data specially suitable for cartographic studies. The possibility of working with data from remote areas, which have not yet been properly mapped, where reference data is hardly available and field work is difficult, is a big challenge for interferometric cartography. The difficulties arise from the fact that there is not an obvious way to combine all the information from different frames to obtain a reliable mosaic DEM of a large area of terrain (let us say 500 Km x 500 Km). Several geometric and radar parameters must be simultaneously adjusted to generate quality topographic information. Some problems that do not need to be taken into account when processing small DEM's are critical when working with large areas divided into several frames.

The Institut Cartogràfic de Catalunya (ICC) has developed an algorithm capable of working with a large set of interferometric pairs for the generation of high-quality maps over remote areas. The processing starts with a classical interferometric step that obtains the unwrapped phases for each interferometric frame. Then, these phases and the system parameters are introduced into a bundle adjustment processor that estimates the optimal values for some critical parameters needed to generate a complete DEM of the area. The main point of the algorithm is the utilization of phase-registered points between different overlapping pairs, ensuring the correct geometry of the scene. Results of the area of Tierra del Fuego (Argentina) are presented using this technique.

II. Data Configuration

The method works with a set of overlapping ascending and descending interferograms previously unwrapped. A Region Growing (RG) algorithm has been selected for this step due to the good results obtained when studying remote areas affected by low coherence [1]. It is usual that the result of the phase unwrapping finishes with several disconnected areas surrounded by low coherence zones. If these areas are close enough, a least-square algorithm estimates the phase offsets and generates a corrected unwrapped phase map of the interferogram. The remaining zones are masked out.

A key point of the presented method is the usage of phase-registered points spread over the area under study. These points are divided into:

- Control points: Information about geographical position and height, column and line into the amplitude image and phase into the interferogram is introduced into the adjustment algorithm. The amount of these kind of points needed to generate large DEM's is very low. In the results presented in section V only six control points have been used.
- Known-height points: Terrain height, column and line, and interferometric phase is used for this kind of points. They are approximately located over the coast line and are easy to identify. No a priori information is needed about their geographical position.
- Corresponding points: These are the most important phase-registered points, because they connect different interferograms and allow to obtain a geometrically continuous map. The information used from these points is the column and line, and phase for both interferograms that form the connected pair. Again, no a priori geographical information is necessary.

Fig. 1 shows the interferogram and phase-registered point distribution for the case under study in Section V. This area corresponds to Tierra del Fuego (Argentina) and has been mapped using 10 ERS SAR interferograms.

III. Geometric Model

The multiple adjustment is based on the estimation of several SAR parameters which are introduced into de geometric model and computed taking advantage of the phase-registered points detailed in the previous section. For the master image these parameters are: the time of the first line, the temporal increment for each line, the slant-range for the first sample, the phase offset of the interferogram and the phase linear terms in range and azimuth for compensating the baseline errors. Only the first three of these parameters are used for the slave image.

It is important to note that unwrapped phase is used during the adjustment processing. Therefore, the output parameters can be directly used for geocoding, because interferometric phases will be calibrated and compensated for baseline errors [2].

The adjustment algorithm has been designed as an iterative process where the column and line errors for the master image are computed jointly with the phase error for each phase-registered point in each iteration. It must be noted that the column and line values for the slave image are obtained through the sup-pixel registration used to create the interferogram. The solution is reached when the adjustable parameters of all the images change only below a certain threshold (convergence). This ensures that the final DEM generated by combining the sub-DEM's will be geometrically correct.

After obtaining the adjusted parameters, the single DEMs must be geocoded. In this case, a forward algorithm has been used for this purpose, directly relating interferometric phases and image position to geographical position.

IV. Mosaicking

Once all the sub-DEMs have been generated using the calibrated parameters, they must be combined to obtain the complete elevation map of the area.

The mosaic process implemented in the presented method utilizes the following information: interferometric coherence and sample redundancy. These two values are used to weight each height obtained from different DEMs, i.e. the final height is computed by combining all the available information. Coherence is directly used as a weight. Therefore, those pixels affected by low coherence will not significantly contribute to the final DEM if other high coherence samples are available. The sample redundancy is also used in the following way: if we have several height values from different sub-DEMs, the weighted average value is computed, where all the samples are weighted using an inverse factor to their difference respect to the average.

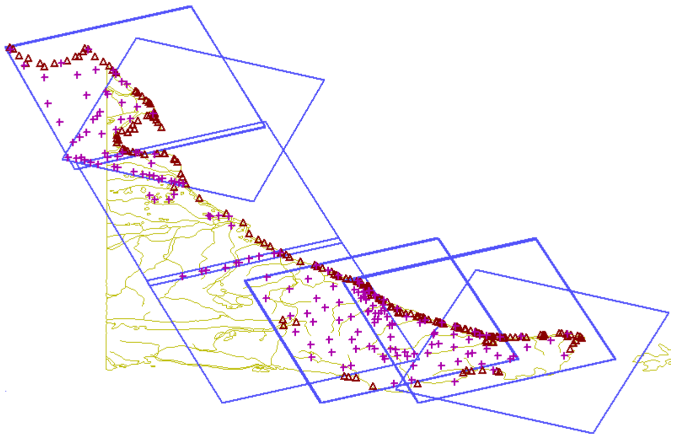

Figure 1. Interferogram and phase-registered point distribution.

TABLE I. List of Tandem Interferograms

	Acquisition dates	Orbit-Frame	Baseline (m)
1	26-27-Oct-1995	22379-6075	84
2	23-24-Jan-1996	23653-6075	157
3	08-09-Feb-1996	23882-6075	161
4	11-12-Feb-1996	23925-6075	104
5	11-12-Feb-1996	23925-6111	100
6	11-12-Feb-1996	23925-6093	102
7	14-15-Feb-1996	23974-4689	143
8	24-25-Feb-1996	24117-4725	195
9	27-28-Feb-1996	24154-6075	46
10	17-18-Mar-1996	24426-6111	42

Using this criteria, an optimum combination of the data is applied. Moreover, over those areas where several sub-DEMs are overlapped, the atmospheric artifacts will be minimized due to data redundancy.

V. Experimental Results

The presented method has been tested with ERS data from the area of Tierra del Fuego (Argentina). This is a very hard zone for generating interferometric topography due to the low coherence that some areas present even with one-day temporal baselines (tandem pairs). Nevertheless, the potentials of this technique arise when using this kind of data in areas that are very hard to map by means of other techniques due to their remoteness or atmospheric conditions. Obviously, areas with low coherence in all the overlapped interferograms will not be mapped and will appear as black holes in the final DEM. Depending on the final purpose of the topographic map, these areas can be filled by interpolation. In the case presented in this paper these areas have not been interpolated in order to clearly show the real extension of the reconstructed map. For this study, the used dataset is composed by 10 tandem interferograms, see Fig. 1 and Table 1.

The phase-registered points are depicted in Fig. 1. It is important to remark that an homogeneous spatial distribution of the points improves the estimation of the parameters, mainly the phase linear terms used to compensate for the baseline errors. After applying the multiple adjustment processor the obtained RMS residual error in the case of control, known-height and corresponding points is showed in Table 2. Note that the column and line error is below one pixel, and the phase error is about one radian, this ensures a correct reconstruction of topography. A column and line error bellow one pixel can be considered an optimum value, taking into account that the precision of the control points over the image can be approximated to 0.5 pixels. On the other hand, the disturbances generated by noise and atmospheric artifacts can produce a phase standard deviation of more than one radian [3].

After the reconstruction of all the sub-DEMs, the final mosaic height map is obtained using the method described in section IV (see Fig. 2). The size of the presented DEM is approximately 350 Km x 350 Km, and its pixel size is 50 m x 50 m. An example of shaded topographic surface of the east part of Tierra del Fuego is shown in Fig. 3. Note that the black areas correspond to sea, lakes and/or layover and low coherence areas. Nevertheless, due to the large overlapping between interferometric tandems, the non-reconstructed areas are significantly reduced.

VI. CONCLUSIONS

The main advantage of SAR interferometry is the possibility of generating very large DEMs of remote areas. Nevertheless, calibration of SAR parameters is critical to generate quality mosaics using single frames. In this paper a new approach to the problem has been presented. The method is based on the use of tie points together with their unwrapped interferometric phases, improving the geometrical results. Experimental results have shown that the proposed approach results in an optimal solution. It is important to remark that the selection of control points is not critical, because a few well-known control points, let us say five, is enough for generating large DEM's. The rest of points, know-height and corresponding, are selected with no a priori geographical information.

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TABLE II. RMS RESIDUAL ERROR FOR CONTROL POINTS

	Control/Known-height	**Corresponding**
Column	0.586 pixels	0.643 pixels
Line	0.229 pixels	0.683 pixels
Phase	0.945 radians	1.159 radians

Figure 2. Complete DEM of Tierra del Fuego (Argentina).

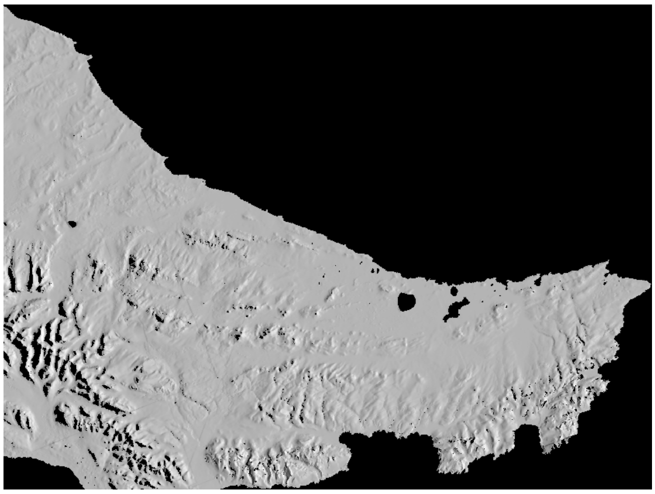

Figure 3. Shaded topographic map of the east part of Tierra del Fuego (Argentina). Black areas correspond to sea, lakes and/or layover and low coherence areas.