RADARGRAMMETRY IMPROVEMENTS: A MULTI-WINDOW APPROACH.

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1. INTRODUCTION

The aim of this paper is to present our studies about extraction of 3D information from radar images. Several radargrammetric methods allow DEM (Digital Elevation Model) generation from SAR images and we take a special interest to the stereoscopic method. So, this paper examines one way to produce DEM (Digital Elevation Models) of a mountainous area (the French Alps) from SIR-C mission data. First, we present the results obtained with a classical radargrammetric method. The results are quite good but errors occur, for example in compressed areas. So, we develop two methods in order to improve the matching step: the correlation surfaces combining method and the expanded correlation windows method. Both of these methods use severals correlation windows for the matching operation. Finally, we expose another improvement combining these two methods.

2. RADARGRAMMETIC CLASSICAL METHOD RESULTS

Our radargrammetric methods are applied on raw data (PR17310 and PR17429) recorded in April, 1994 by the shuttle Endeavour during the SIR-C mission. The two radar images are recorded with 35^o and 50^o incidence angles, that is a good configuration to apply radargrammetric techniques. We prefer to deal with mountain areas (french alpins) in order to get elevation information and the opportunity to compare it with the IGN maps. We obtained first results by using preprocessed radar images [1, 2] that consists in:

1. describing the radar image taking into account the co-ordinates of the pixels by interpolating the satellite trajectory between known position and velocity data of the satellite,

2. calculating the epipolar lines [3] that moreover allows to detect differences between the actual and the calculated positions of GCPs (Ground Control Points). These differences allow to correct the co-ordinates of the radar image,

3. applying a filter in order to reduce the radiometric effect of the speckle (in our case, a Lee filter [4] using a 5 by 5 pixels window is applied, so the edges are preserved).

At this step, we obtain preprocessed images to which the specific radargrammetric processing is applied: matching processing, disparity map and terrain elevation. After computing the matching operation, we obtain the disparity map. However, the values of disparity should be considered according to the confidence in correlation coefficient. The highest value inside a correlation surface can be perfectly detected and the corresponding position is obvious: this corresponds to a high confidence of correlation. In some cases, this maximum position cannot clearly obtained and the confidence correlation is considered as low. For such cases, pyramidal procedure [5] (that improves the disparity map) should strengthen the correlation results. Thanks to the disparity map, we can reconstruct the terrain elevation by resolving the 3D stereo configuration system [2]. Thus, for each point, we obtain the co-ordinates (x, y, z) which are described in the geocentric reference as latitude ϕ, longitude λ and height h. These co-ordinates are compared with the actual terrain model. In order to quantify the accuracy of our elevation reconstruction, we compare it with the SRTM (Shuttle Radar Topography Mission) DEM. The first results (see table 1) of the comparison with the SRTM DEM show that an error of height reconstruction of less than 100 meters occurs for only 83.9 per cent of pixels. Moreover, only 95.0 per cent of pixels exhibit an error less than 200 meters. Considering the relief type and the resolution values, these results are worse but close to the results obtained by other studies [6, 7].

Pyramidal step	pixels with altimetric error			
	< 20m	< 50m	< 100m	< 200m
first step	9.2 %	21.7 %	39.8 %	72.2 %
final step	34.7 %	63.7 %	83.9 %	95.0 %

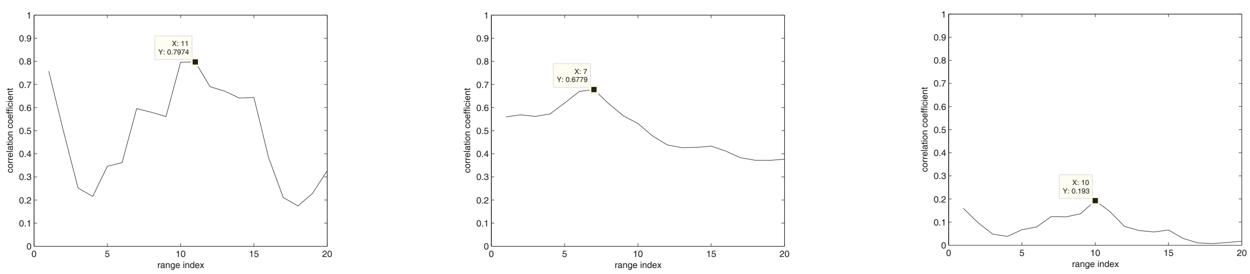
Table 1. Classical technique: reconstruction errors of the generated DEMs

Pyramidal step	pixels with altimetric error			
	< 20m	< 50m	< 100m	< 200m
first step	17.3 %	44.8 %	74.2 %	93.5 %
final step	35.5 %	65.7 %	87.0 %	96.5 %

Table 2. Correlation surfaces combining: reconstruction errors of the generated DEMs

3. FIRST IMPROVEMENT METHOD: CORRELATION SURFACES COMBINING

To improve DEM accuracy, we need to collect more information through the matching process in order to make this step more reliable. We previously used an unique size $n \times m$ for the correlation windows: 23×23 pixels. The use of several correlation window sizes provide us additional information. So, we use four correlation windows: 23×23 pixels, 19×19 pixels, 13×13 pixels and 7×7 pixels. For each window size, we compute the cross-correlation coefficients and we get a correlation surface sorting the values of these coefficients ρ [8]. In figures 1(a) and 1(b), we represent profiles in the range direction of the surfaces obtained for the 7×7 pixels and 23×23 pixels windows. These results mismatch because the range indexes are obviously differents: 11 for the 7×7 pixels window and 7 for the 23×23 pixels window. It's difficult to determine which index is the one corresponding to the true matching pixel. So we combine the different information of each correlation surfaces by multiplying them together to obtain a unique surface. In figure 1(c), we represent a profile of this product surface in the range direction. The values of this surface are used as a confidence level for the correlation and the maximum value of confidence defines the matching pixel.



(a) 7×7 windows size
(b) 23×23 windows size
(c) product of profiles

Fig. 1. Correlation surfaces combining: range profiles

We apply this method of correlation surfaces combining to the whole study area to generate a DEM. The reconstruction errors of this DEM are summarized on table 2. This new method using several window sizes improves the results compared with those described on table 1. For the first step of the pyramidal technique, the results are much improved: for example, we obtain 74.2 per cent of pixels with an error less than 100 meters instead of 39.8 per cent. For the final step, the results are only less 3 per cent better in comparison with those firstly described.

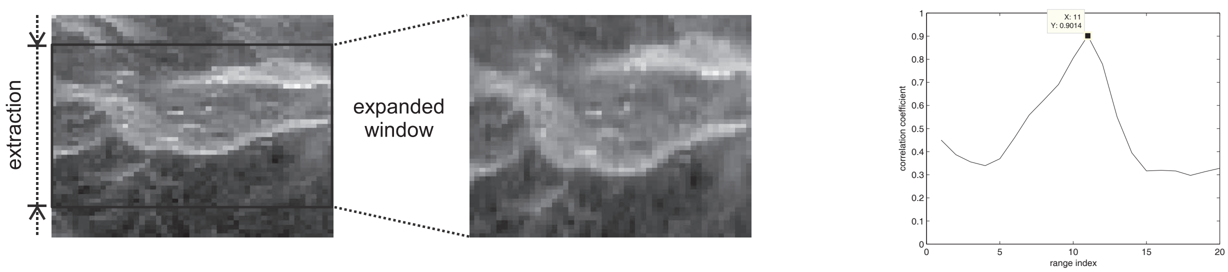
4. SECOND IMPROVEMENT METHOD: EXPANDED CORRELATION WINDOWS

The generated DEM still not enough accurate because the matching operation tends to fail for pixels located in compressed areas. For such areas, the incidence angle difference between the two images involves a higher range difference between the two SAR images (the primary and the secondary ones). As a consequence, the correlation windows are not similar enough to provide a reliable matching. In order to avoid matching mistakes, the correlation windows size n is reduced along the range axis depending on the range compression. For this method, the reduction is applied to the only one 23×23 pixels window size. So, we obtain differents compressed windows sizes $n \times m$ from 13×23 to 23×23 pixels. Then, we upscale these windows

Pyramidal step	pixels with altimetric error			
	< 20m	< 50m	< 100m	< 200m
first step	21.9 %	52.9 %	85.9 %	99.4 %
final step	46.1 %	86.2 %	97.9 %	100.0 %

Table 3. Expanded correlation windows: reconstruction errors of the generated DEMs

to recover the original size (23×23 pixels) in order to compute the cross-correlation coefficients between windows of identical size. This method is illustrated on figure 2(a). We can see the new range profile for the 23×23 windows size on figure 2(b) to be compared with the profile in figure 1(b). The maximum value of correlation coefficient is 0.90, located at the range index 11 instead of 0.68 at the range index 7. The index has been corrected and the confidence value is better.

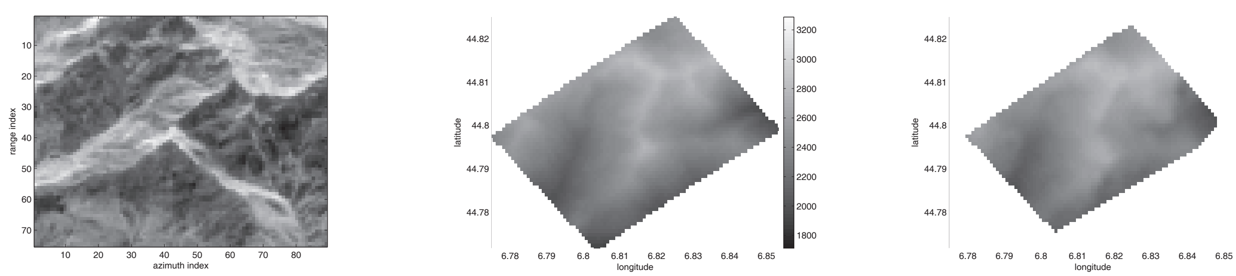


(a) Representation of methodology

(b) 23×23 windows size range profile

Fig. 2. Expanded correlation windows method

Therefore, we apply this new procedure to the entire image (see figure 3(a)). In order to quantify the accuracy of our elevation reconstruction, we compare the SRTM DEM (figure 3(b)) with our generated DEM (figure 3(c)). So, the ground resolution is 93 meters, corresponding to the SRTM data. The results of this comparison, exposed on table 3, show that an error of height reconstruction less than 100 meters occurs for 97.9 per cent of pixels, for the final pyramidal step. Thus, we note a significant improvement of the reconstruction accuracy that can be compared with results obtained with more sophisticated methods [9, 10, 11] applied on such relief areas.



(a) PR17310 image extract

(b) SRTM DEM

(c) Generated DEM

Fig. 3. Working area image, SRTM DEM and generated DEM

5. COMBINING BOTH IMPROVEMENT METHODS

To take advantage of the two described methods, we decide to combine them in order to improve DEM reconstruction accuracy. We apply the both methods to the whole working area in order to generate a DEM. The reconstruction errors of this DEM are summarized in table 4. For the final pyramidal step, the results are strictly identical to the results obtained by applying only the expanded correlation windows method. Otherwise, at the first pyramidal step, we notice an improvement of accuracy: 94.8 per cent of pixels with an error less than 100 meters instead of 85.9 per cent. So, at this step, the disparity map generated combining

Pyramidal step	pixels with altimetric error			
	< 20m	< 50m	< 100m	< 200m
first step	30.4 %	67.7 %	94.8 %	99.5 %
final step	46.1 %	86.2 %	97.9 %	100.0 %

Table 4. Combining both improvement methods: reconstruction errors of the generated DEMs

both methods is more accurate and reliable than the disparity map generated by using only the expanded correlation windows method. From these different disparity maps, the pyramidal scheme leads to the same results at the final step. However, if computing time is not limitative, we recommend to combine the two improvement methods in order to ensure maximum accuracy and reliability through the process.

6. CONCLUSION

This paper deals with the relevance of using stereoscopic radar images in order to retrieve the relief of terrain. Firstly, the basic characteristics of the radargrammetry are described. Thus, we present the results of the radargrammetric classic method applied to radar images, recorded by the SIR-C mission over the French Alps. The results show that the image matching can fail, especially in compressed areas. So, we expose two different improvement methods using several correlation windows in order to cancel the reconstruction errors. The first improvement take advantage of a multi-window approach to combine information multiplying the correlation surfaces obtained for each correlation window size. The second improvement is based on another multi-window approach that makes it possible to get correlation windows adapted to the compressed areas. Finally, we combine these two improvement methods to show that it's possible to make the disparity map more reliable at the first step of the pyramidal scheme.

7. REFERENCES

[1] F. Fayard, S. Méric, and E. Pottier, "Matching stereoscopic sar images for radargrammetric applications," in *IEEE International Geoscience and Remote Sensing Symposium*. IGARSS, 2007, pp. 4364 – 4367.

[2] S. Méric, F. Fayard, and E. Pottier, *Geoscience and Remote Sensing*, chapter Radargrammetric SAR image processing, pp. 421 – 454, In-Tech, 2009.

[3] Z. Zhang, R. Deriche, O. Faugeras, and Q.T. Luong, "A robust technique for matching two uncalibrated images through the recovery of the unknown epipolar geometry," *Artificial intelligence*, vol. 78, pp. 87 – 119, 1995.

[4] Lee J.S, "Refined filtering of image noise using local statistics," *Computer Graphics and Image Processing*, , no. 15, pp. 380 – 389, 2000.

[5] M. Denos, "A pyramidal scheme for stereo matching sir-b imagery," *International Journal of Remote Sensing*, vol. 13, no. 2, pp. 387 – 392, 1992.

[6] P. Paillou and M. Gelautz, "Relief reconstruction from sar stereo pairs: the "optimal gradient" matching method," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 37, no. 4, pp. 2099 – 2107, 1999.

[7] T. Toutin and L. Gray, "State-of-the-art of elevation extraction from satellite sar data," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 55, pp. 13 – 33, 2000.

[8] F. Leberl, K. Maurice, J.K. Thomas, and M. Millot, "Automated radar image matching experiment," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 49, no. 3, pp. 19 – 33, 1994.

[9] G. Oller G, P. Marthon, and L. Rognant, "Edge detection and extraction for sar images," in *Geoscience and Remote Sensing Symposium*. IGARSS, 2003, vol. 6, pp. 4004 – 4006.

[10] Y. Belgued, E. Hervet, C. Lemarchal, L. Rognant, P. Marthon, and F. Adragna, "An accurate radargrammetric chain for dem generation," in *CEOS Committee on Earth Observation Satellites*, 1999, vol. 450, p. 167.

[11] B. Pradhan, T. Bolch, and M.F. Buchroithner, "Elevation modeling using radargrammetry: case of study from malaysia," in *Proc. 12th AGILE International Conference on Geographic Information Science*, 2009, vol. 6419, pp. 641906.1 – 641906.8.