GENERATION OF DEM BY RADARGRAMMETRIC TECHNIQUES

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1. INTRODUCTION

Thanks to the signal processing applied to radar signal [1], radar systems can provide images with a very high resolution. With regard to these properties, one can estimate that radar images are used to get elevation terrain considering the basic characteristics of a radar image. This paper examines one way to produce DEM (Digital Elevation Models) from a mountainous area (the French Alps). So, we organize the discussion in three parts. First, we present the basic operations that the radargrammetric processing requires to be performed. So we deal with the different steps to obtain a DEM. Secondly, we expose two classical image matching improvements: the epipolar geometry and the pyramidal scheme. At the end, we present the results of DEM generation from a SIR-C shuttle mission image pair and the way to improve these results.

2. RADARGRAMMETRIC PRINCIPLES

The definition of radargrammetry has been stated by Leberl [2]: "Radargrammetry is the technology of extracting geometric information from radar images". The main parameters used by stereoscopic method are parallax and convergence angle. These parameters are described in figure 1 assuming a same-side stereoscopic configuration. The parallax P of an observed point is directly connected to the point elevation and it increases with the altitude of the point. The convergence angle $\Delta\theta_v = \theta_{v1} - \theta_{v2}$ is defined by the intersection of the two lines of sight of the radar and this angle increases as the baseline B_s rises.

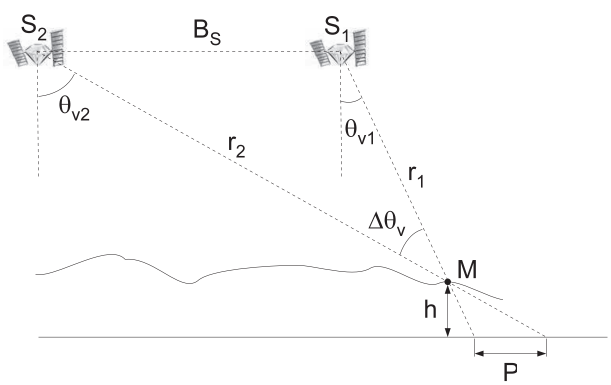


Fig. 1. One radar stereoscopic configuration

The main processing steps to generate DEM from stereo radar images by radargrammetry are shown in figure 2. First, the image matching allows to find correspondances between SAR images ant to generate the disparity map. Second, the 3D stereo intersection makes it possible to extract height from the disparity map to generate the raw DEM. Finally, the DEM is geocoded and filtered. Also, GCPs (Ground Control Points) are collected to refine the geometric model and to correct localisation errors.

2.1. Image matching

In radargrammetric processing, a critical step is to obtain a disparity map directly linked to the parallax of each pixel of the radar image. This disparity map is provided through the matching step applied to the stereoscopic radar images pair (called

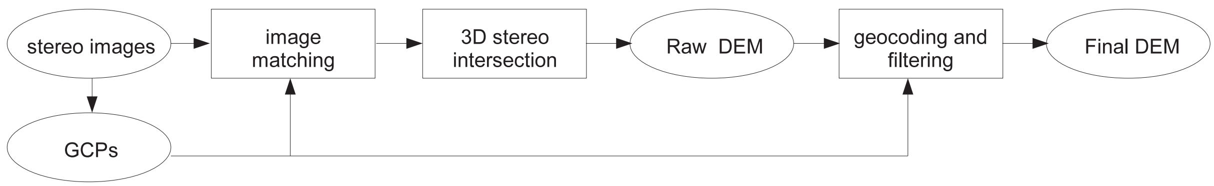


Fig. 2. Shematic representation of methodology

the primary and secondary images). The most common image matching method is area correlation achieved by the zero-mean normalized cross-correlation (ZNCC) that gives the cross-correlation coefficient ρ:

$$\rho = \frac{E\left[I_1 I_2\right] - E\left[I_1\right] E\left[I_2\right]}{\sqrt{V(I_1)V(I_2)}} \tag{1}$$

where I_1 and I_2 represent respectively the amplitude value of the primary and the secondary image window. Windows have the same range and azimuth sizes; the expression of $E[.]$ and $V[.]$ gives respectively the mean expectation and the variance expression. Then, we get a correlation surface obtained with the values of the coefficient ρ [3]. The maximum value of this surface gives the position of the better candidate pixel (called the homologous pixel) for the matching operation in the secondary image. The range and azimuth indexes of the homologous pixel make it possible to compute the disparity.

2.2. 3D stereo intersection

For each pixel in the primary image, the disparity value gives the relation between the values r_1 and r_2. Moreover, in the radar image, a pixel is referenced by its range and azimuth indexes. On the one hand, the range distance locates the point on a range sphere that the centre is the radar position: this is the range sphere. On the other hand, the azimuth position of a pixel can give the Doppler cone which is replaced by a plane in our case because of the null Doppler frequency at the perpendicular direction of the radar beam. The intersection of the range sphere and the Doppler plane provides two solutions but only one is obviously the good one according to the direction of the radar beam. The solution (x, y, z) of the search point satisfies the following equations system:

$$\left\{\begin{array}{lcl} (x-X_1)^2 + (y-Y_1)^2 + (z-Z_1)^2 & = & r_1^2 \\ (x-X_1)\dot{X}_1 + (y-Y_1)\dot{Y}_1 + (z-Z_1)\dot{Z}_1 & = & 0 \\ (x-X_2)^2 + (y-Y_2)^2 + (z-Z_2)^2 & = & r_2^2 \\ (x-X_2)\dot{X}_2 + (y-Y_2)\dot{Y}_2 + (z-Z_2)\dot{Z}_2 & = & 0 \end{array}\right. \tag{2}$$

where the position $(X_{1,2}, Y_{1,2}, Z_{1,2})$ and the velocity $(\dot{X}_{1,2}, \dot{Y}_{1,2}, \dot{Z}_{1,2})$ of the radar are required to obtain a solution. Also, the raw DEM is directly obtained by resolving the system (2) for the all pixels of the radar image.

2.3. DEM geocoding and filtering

The raw DEM contains 3D points with the co-ordinates (x, y, z). Geocoding consists in describing these co-ordinates in the geocentric reference as latitude ϕ, longitude λ and height h. Moreover, we use a low-pass Wiener filter to eliminate residual errors. The geocoding operation makes it possible to compare the geocoded DEM with the actual terrain model. In order to quantify the accuracy of our elevation reconstruction, we compare it with a SRTM (Shuttle Radar Topography Mission) DEM.

3. CLASSICAL IMAGE MATCHING IMPROVEMENTS

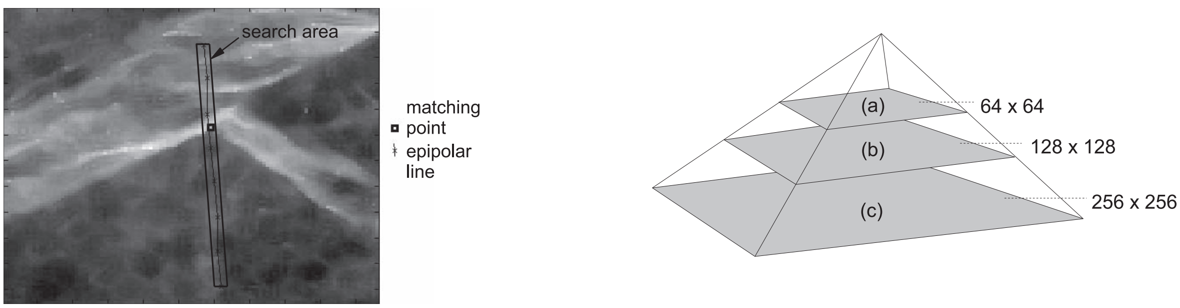
The crucial step in radargrammetry technique is the image matching: the generated disparity map must be accurate and reliable to avoid DEM reconstruction errors. So the image matching can be improved using epipolar geometry and pyramidal scheme. These techniques make it both possible to save computation time and to reduce false matching.

3.1. Epipolar geometry

The image matching is a time-cost process because the computation of ZNCC in equation (1) is time-consuming and we need to find homologous pixels on a large area. Using the epipolar geometry [4], we can reduce the search area. So, we describe the viewing geometry taking into account the co-ordinates of the points as well as the satellite trajectory and satellite velocity data. For each image point, the co-ordinates (x, y, z) satisfy the following equations system:

$$\left\{ \begin{array}{lcl} (x-X_i)^2+(y-Y_i)^2+(z-Z_i)^2 & = & r_i^2 \\ (x-X_i)\dot{X}_i+(y-Y_i)\dot{Y}_i+(z-Z_i)\dot{Z}_i & = & 0 \\ \dfrac{x^2+y^2}{(a+h)^2}+\dfrac{z^2}{(b+h)^2} & = & 1 \end{array} \right. \quad (3)$$

where the Earth ellipsoid parameters are: $a = 6378137.0$ meters and $b = 6356752.3$ meters. To draw the epipolar line associated to a pixel, it's necessary to make the height h vary from h_{min} to h_{max}, which ones are estimated observing the study area. For a given pixel on an image, the corresponding pixel in the secondary image locates on this epipolar line. Ideally, the search area can be reduced on a thin strip of one pixel thickness on the epipolar line. Practically, it's preferable to have a reduced search area of three pixels length in the azimuth direction, as shown in figure 3(a). Indeed, a safety margin is required because estimation errors on the epipolar line can lead to mistaken parameters. Finally, the epipolar geometry considerably reduces the size of the search area in both range and azimuth directions.



(a) Epipolar search area

(b) Pyramidal scheme with growing resolutions

Fig. 3. Classical techniques to improve image matching

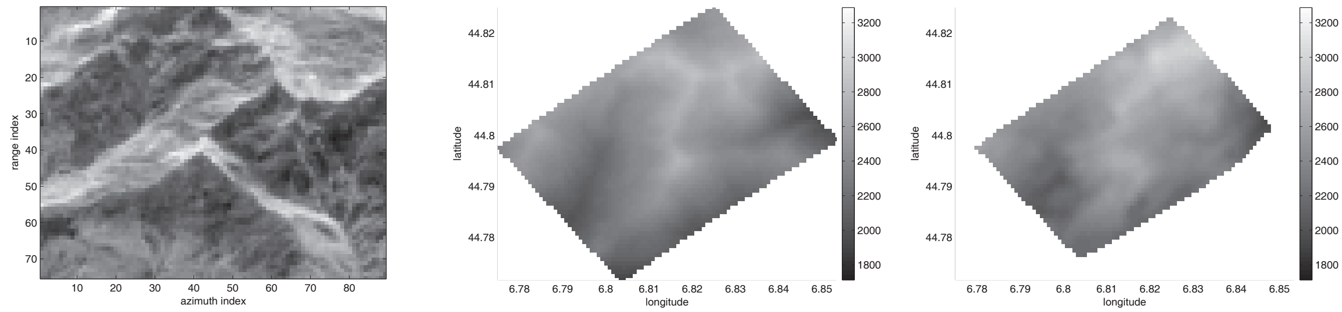
3.2. Pyramidal scheme

A hierarchical strategy is used to reduce process time and allows to work on large images: the pyramidal scheme [5]. The principle is quite simple: from the original image we build an image pyramid, as shown in 3(b). At each level, the image size is reduced by a factor 2^k corresponding to the k-iteration step. The images are reduced by averaging the pixels gray levels: in the reduced image, each pixel value is the average of four pixels in the previous image. For each iteration, the matching process establishes an approximate disparity map. Specially for the first iteration, this disparity map is no enough regular because of disparity jumps between neighbouring pixels. So, we use a low-pass Wiener filter to make this disparity map more regular. Thus, we are able to predict the disparity offsets at the next level of the hierarchical process, reducing computation time and speckle errors. With increasing iterations, we obtain a better accuracy for each level. At the final step, the last disparity map is used to produce the DEM, according to equations (2).

4. RESULTS

This part is dedicated to the application of the radargrammetric operations 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 (the French Alps) in order to get elevation information and the opportunity to collect GCPs thanks to the IGN (National Geographic Institute) maps [6]. We can see in figure 4(a) the working area on which the radargrammetric processing is applied.

To quantify the accuracy of our elevation reconstruction, we compare the SRTM DEM (figure 4(b)) with our generated DEM (figure 4(c)). So, the ground resolution is 93 meters, corresponding to the SRTM data. The results of this comparison, exposed on table 1, show that an error of height reconstruction less than 100 meters occurs for 83.9 per cent of pixels, for the final step. Moreover, 95.0 per cent of pixels exhibit an error less than 200 meters. Considering the relief type and the resolution values, these results are close to the results obtained by other studies [7, 8, 9]. The table also highlights the evolution of accuracy through the pyramidal steps: the first step provides an approximate disparity map, which is refined in the following steps.



(a) PR17310 image extract (b) SRTM DEM (c) Generated DEM

Fig. 4. Working area image, SRTM DEM and generated DEM

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

5. CONCLUSION

This paper deal 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: we present the radargrammetric method applied to radar images. In the second part, we expose an improvement of the matching operation in order to save computation time and to reduce false matching. Finally, we illustrate radargrammetric processing by using SIR-C data over the French Alps. The generated DEM by our radargrammetric method is quite similar to the SRTM DEM. However, the generated DEM is not enough accurate because the matching operation tends to fail for pixels located in compressed areas. Our current studies focus on this point using several correlation sizes through a multi-window approach, especially expanding window sizes in range direction.

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