ABSTRACT

The availability of new high resolution radar spaceborne sensors offers new interesting potentialities for the acquisition of data useful for the generation of Digital Surface Models (DSMs).

Two different methods may be used to generate DSMs from Synthetic Aperture Radar (SAR) data: the interferometric and the radargrammetric approach.

It is well known that the two main steps for DSMs generation from SAR imagery according to the radargrammetric approach are the stereo pair orientation and the image matching.

In this paper the topics related to image orientation of SAR stereo pairs in zero-Doppler geometry acquired by COSMO-SkyMed sensor in Spotlight mode are investigated. An orientation model has been implemented in a scientific software developed by research team at Geodesy and Geomatic Area of University of Rome “La Sapienza”.

To test the effectiveness of the new model a stereo pair, acquired by COSMO-SkyMed in Spotlight mode over the test site of Mausanne (South France), has been orientated varying the number of Ground Control Points (GCPs).

The results are also compared to the ones, obtained through the commercial software OrthoEngine 10.2 (PCI Geomatics), in which the model developed by T. Toutin is embedded.

1. INTRODUCTION

An important part of the international research and development (R&D) programs are related to the DSMs generation from satellite data, both optical and SAR.

DSMs extraction from satellite stereo pair offers some advantages, among which low cost, speed of data acquisition and processing, availability of several commercial software and algorithms for data processing. In particular, the DSM extraction from SAR data offers the significant advantage of possible acquisition during the night and in presence of clouds.

Two different methods to extract absolute or relative elevation from SAR data are interferometry and radargrammetry, both using a couple of images of the same area acquired from two different points of view. The interferometry uses the phase differences information between the SAR images to lead the terrain elevation, unlike radargrammetric technique analyzes the signal amplitude and exploits the stereoscopy similarly to optical photogrammetric methods.

The radargrammetric approach was first used in the 1950s; then it was less and less used, due to the quite low resolution in amplitude of radar image, if compared to their high resolution in phase. Only in the last decade some researchers have investigated the DSMs generation from SAR data acquired by the various sensors presently available: several results about data acquired by lower resolution satellite, as RADARSAT and ERS1/2, have been published by Toutin in [6] and quite recently Raggam et al. [5] studied the potentialities of TerraSAR-X, as regards high resolution SAR satellite operating in Spotlight mode.

At present, the importance of the radargrammetric approach is rapidly growing due to the new high resolution imagery (up to 1 m GSD) which can be acquired by COSMO-SkyMed, TerraSAR-X and RADARSAT-2 sensors in Spotlight mode. In this sense, it seems useful to underline that the two approaches should be considered complementary, in order to obtain the best (accurate and complete) product [1].

To obtain good stereo geometry, the optimum configuration for the radargrammetric application is when the target is observed in opposite-side view; however it causes large geometric and radiometric disparities hindering image matching. A good compromise is to use a same-side configuration stereo pair with a base to height ratio ranging from 0.25 to 2 [4] in order to increase the efficiency in the correlation image process.

As regards the radargrammetric orientation model, it has to be underlined that, starting from the model proposed in the classical book of Leberl [2], a refinement of the orbital model is needed to comply with and to exploit the potentialities of the novel high resolution (both in azimuth and in range). Then, the defined and implemented model performs a 3D orientation based on two range and two zero-Doppler equations, allowing for some calibration parameters least squares estimation, related to satellite position and velocity.
2. THE RADARGRAMMETRIC MODEL

The orientation model implemented is based on rigorous radar projection equations, similar to the so-called rigorous photogrammetric equations for the optical sensors. The radargrammetry technique performs a 3D reconstruction based on the determination of the sensor-object stereo model, in which the object position is computed by the intersection of two radar rays with two different look angles.

First of all it necessary to recall the meaning of a slant range projected SAR image. The image system adopted is a 2-dimensional system describing a point position in an image, the origin is in the upper left corner, the pixel position is defined by its line (\(J\)) and sample (\(I\)). The line numbers increases toward the right and sample numbers increases downwards. The line position is related to the acquisition time, measured along the flying direction of the satellite, called azimuth direction; the sample position is related to the slant range of each point, that is the distance between the satellite and the ground point.

Correspondingly, the pixel dimension is characterized by two different resolutions: the azimuth resolution in flying direction (\(\text{line spacing } LS\)) and the slant range resolution in the slant range direction (\(\text{column spacing } CS\)).

The radargrammetric geometric constraint equations read:

\[
\begin{align*}
\hat{v} \cdot (\vec{S} - \vec{P}) &= 0 \\
|\vec{S} - \vec{P}| &= R_{S_P}
\end{align*}
\]

where (if expressed in a cartesian local system, as usually done for convenience): \(\vec{P}\) is the 3D position of a generic ground point \(P\) in the local system, \(\hat{v}\) is the 3D velocity unit vector, \(\vec{S}\) is the 3D position of satellite in the local system corresponding to the point \(P\), \(R_{S_P}\) is the slant range related to the generic point \(P\).

The first equation of (1) represent the general case of zero-Doppler projection: in zero-Doppler geometry the target is acquired on a heading that is perpendicular to the flying direction of the satellite [3].

The second equation of (1) is the slant range constrain, which in explicit form reads:

\[
(\chi - \chi_0)^2 + (\chi - \chi_0)^2 + (\chi - \chi_0)^2 - (D_s + CS \cdot I) = 0
\]

where: \(D_s\) is the slant range reference, that is the slant range corresponding to the side of the image nearest to the satellite, \(CS\) is the column spacing, \(I\) is the column position of point \(P\) on the image.

In order to compute the satellite position for each image point, a crucial step is the reconstruction of the orbital segment during the image acquisition, through knowledge of orbital parameters.

Since the orbital arc related to the image acquisition in Spotlight mode is relatively short (about 10 Km), it could be conveniently modelled with a circular arc; its parameters are estimated by least squares adjustment using few orbital state vectors available in the metadata.

The GCP are employed in order to estimate a linear relation between time of acquisition and line position on the image (3), and to estimate the value of the slant range reference \(D_s\).

\[
t = k_{10} + k_{11} \cdot J
\]

3. RESULTS

3.1. Data set

The available images for the experimentation are two COSMO-SkyMed Spotlight images acquired over the area of Mausanne (South France). The images belongs to the Level 1A (SCS) category products, that is focused data in complex format, in slant range and zero-Doppler projection.

The two scenes were acquired with incidence angles of 35.7 and 55.4 degrees respectively along an ascending orbit, forming a same-side configuration stereo pair. The area covered by the stereo pair is approximately 10×10 Km².

The stereo pair orientation is based on 25 Ground Points (GPs). For 23 GPs the coordinates have been computed by stereo restitution, using a Cartosat-1 stereo pair, acquired in the frame work of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) and previously oriented with 17 GCPs collected with GPS surveys; the mean horizontal and vertical accuracy of these 23 GPs are 3.0 and 4.0 m respectively.

In this respect, unfortunately the coverage of COSMO-SkyMed image is less extended than the Cartosat-1 one and only two GPS GPs used for Cartosat-1 orientation are visible in the COSMO-SkyMed stereo pair.

3.2. Accuracy results

To test the effectiveness of the new model, the stereo pair has been orientated varying the number of GCPs and the model accuracy is analyzed, evaluating the RMSE computed over Check Points (CPs) residuals (RMSE CP).

In order to obtain significant results from the statistical point of view, for a given number of GCPs, different tests were carried out, using independent sets of GCPs.
### Table 1 Scientific software results

<table>
<thead>
<tr>
<th># GCPs</th>
<th>NORTH [m]</th>
<th>EAST [m]</th>
<th>UP [m]</th>
<th>average [m]</th>
<th>median [m]</th>
<th>standard deviation [m]</th>
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<tbody>
<tr>
<td>3</td>
<td>5.46</td>
<td>5.15</td>
<td>5.17</td>
<td>5.46</td>
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<td>5.13</td>
<td>4.26</td>
<td>4.50</td>
<td>5.05</td>
<td>0.40</td>
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<tr>
<td>9</td>
<td>4.50</td>
<td>4.37</td>
<td>4.49</td>
<td>4.99</td>
<td>4.64</td>
<td>0.72</td>
</tr>
<tr>
<td>12</td>
<td>4.20</td>
<td>5.48</td>
<td>4.23</td>
<td>4.20</td>
<td>5.48</td>
<td>0.55</td>
</tr>
<tr>
<td>16</td>
<td>4.53</td>
<td>4.32</td>
<td>3.73</td>
<td>4.53</td>
<td>4.32</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>5.74</td>
<td>4.67</td>
<td>4.77</td>
<td>5.74</td>
<td>4.67</td>
<td>-</td>
</tr>
</tbody>
</table>

### Table 2 OrthoEngine results

<table>
<thead>
<tr>
<th># GCP</th>
<th>North[m]</th>
<th>East[m]</th>
<th>Up[m]</th>
</tr>
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<td>3</td>
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<td>4.55</td>
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<td>5.09</td>
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<tr>
<td>25</td>
<td>-</td>
<td>-</td>
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</table>

The horizontal and vertical accuracy are both at level of 4.0 - 5.0 m, basically at the same accuracy of the GPs, if the error due to their recognition on the COSMO-SkyMed images is considered; as regards the model performance achievable varying the set of GCPs, the software shows a stable behavior and the increasing of GCPs number does not improve the results remarkably.

Moreover, also the best results obtained using the commercial software OrthoEngine 10.2 (PCI Geomatics), in which the model developed by T. Toutin is embedded, are presented in the Table 2.

### 4. CONCLUSIONS

A new model for the orientation of stereo pairs collected by COSMO-SkyMed sensor in Spotlight mode was defined and implemented.

An experiment was carried out with a stereo pair collected over the test site of Mausanne (South France), where GPs derived from a previous study on a Cartosat-1 stereo pair.

The accuracy evaluation shows that the horizontal and vertical accuracy are both at level of 4.0 - 5.0 m; this preliminary results are satisfying, considering the mean accuracy of the available GPs. An investigation using more accurate GPs, for example GPS points, is necessary. The model behaves quite stable with better results if compared to the commercial software OrthoEngine 10.2.

### 5. ACKNOWLEDGEMENTS

The COSMO-SkyMed stereo pair was made available by e-Geos S.p.A., Rome (Italy), in the frame of a collaboration agreement; the Authors are indebted to e-Geos S.p.A. for this.

### 6. REFERENCES


