AN EMPIRICAL MODEL FOR ORIENTATION OF
ALOS-PRISM IMAGES OF LEVEL 1B2

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ABSTRACT:

The Japanese satellite ALOS incorporates the PRISM sensor, dedicated to high resolution stereo imaging. It has a potential to derive elevation data compatible with medium scale topographic mapping scales, such as 1:25,000 or even larger. Being dedicated to systematic stereo coverage it can contribute for topographic mapping purposes in many undeveloped regions of the world.
Rigorous photogrammetric treatment is not always a simple task for many users, for several reasons. This paper presents a methodology of image orientation using an alternative empirical sensor model, applicable to images of processing level 1B2. It is based on adjustments in image space and in height determination by a linear relation with parallax. It uses the approximate geo-location information derived from the sensor navigation instruments, provided with images
Tests were realized with PRISM images of a relatively mountainous region in Portugal. A total of 50 accurate ground control points (some used as check points) were used to test the proposed method. The overall accuracy, assessed with 41 independent check points, was of 2.1 m for the planimetry and 2.6 m for height. These results are slightly worse than the ones referred in the literature for precise sensor models, but compatible with the standards for 1:25,000 scale mapping.

1. INTRODUCTION

The PRISM sensor on board of Japanese ALOS satellite is fully dedicated to the acquisition of high resolution stereo imagery. It is composed by a triple line scanner, that provides along-track overlapping images with 3 different viewing angles (forward, nadir and backwards). Its high resolution, with a ground sampling distance (GSD) of 2.5 meters, has a good potential for relief mapping with a positional accuracy compatible with scale 1:25,000 (Takaku et al., 2005, Takaku and Tadono, 2007). Topographic mapping at this scale is very important for planning purposes and most of the undeveloped areas in the world are not mapped at any scale better than 1:100,000.

Photogrammetric mapping from this type of sensors requires appropriate sensor models. That is the case, for example of program SAT-PP, developed at ETH-Zurich (Kocaman and Gruen, 2007), which does a rigorous mathematical modelling of the sensor geometry. However, very specific algorithms are not available to many users. A possible solution for mapping from ALOS-PRISM is the use of Rational Polynomial Coefficients (RPC), which make it possible to do a rigorous treatment in a generic software. However, RPC coefficients are not provided by the Japanese Space Agency (JAXA) with all images.

Another limitation is that photogrammetric mapping from PRISM requires images in original sensor geometry. These correspond to processing levels 1A or 1B1, but many images are provided in processing level 1B2, which went through a geometric rectification to a map projection.

This paper deals with an empirical sensor model applicable to images of processing level 1B2. Images were projected from sensor geometry onto the reference ellipsoid and then mapped to a standard map projection, normally UTM. These are similar to other high resolution images, such as Ikonos, which are provided in a mode called GEO, which is also in a UTM projection. Orientation of these images is based on adjustments in image space. (Fraser and Hanley, 2003, Grodecki and Dial, 2003).

In the proposed method a similar procedure is applied with ALOS-PRISM nadir image. It can in general be applied to optical satellite images due to some particular conditions which allow for some simplification and approximations, (Gonçalves, 2005). These conditions are described below

2. SENSOR MODEL FOR THE NADIR IMAGE

The PRISM images available for this project were of mode 1B2-R, in which images are resampled to a UTM projection. Images are projected onto the ellipsoid level (Saunier et al., 2007), using the rigorous sensor geometry, and then projected to UTM, in the same manner as with other high-resolution imagery. The approximate exterior orientation (sensor position and attitude), is considered. However, in image mode 1B2-R, the image still needs to be rotated to become aligned with UTM axes, so image lines approximately coincide with image lines in the original sensor geometry.

An approximate sensor model was developed to deal with these images, not making use of co-linearity equations. Several aspects of PRISM images, such as the very narrow field of view (2.9°), the fact that a very good initial orientation is known and that terrain height is much smaller than the satellite altitude allow for important approximations by linear relationships.

2.1 Object to image projection for the Nadir image

Sensor model equations establish a projection from object to image space. That will be done stepwise for the 1B2-R images, considering an estimation of relief displacement and additional positional corrections. The sensor model is established for the nadir image.

Within the image ancillary data, an affine formula is given to convert from image coordinates to UTM and vice-versa (equation 1).

$$\begin{pmatrix} x_0 \\ y_0 \end{pmatrix} = \begin{pmatrix} A_1 & A_2 \\ A_3 & A_4 \end{pmatrix} \begin{pmatrix} E \\ N \end{pmatrix} + \begin{pmatrix} A_5 \\ A_6 \end{pmatrix} \qquad (1)$$

where (x_0,y_0) are the predicted image coordinates, $(A_1,\ldots, A_6)$ are the given parameters and (E,N) are the UTM coordinates in Km (more precisely the E coordinate does not include the false easting of 500 Km). This relation is not exact due to the relief displacement and due to the inaccuracy of the initial exterior orientation. Figure 1 represents the displacement suffered by an object of height h. This effect can be estimated from equation (2), using the local incidence angle.
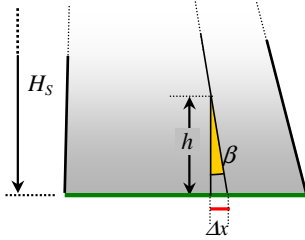

Figure 1. Relief displacement of an object with height h.

The corrected image coordinate, x'_0,

$$x'_0 = x_0 + \Delta x = x_0 + \frac{h \cdot \tan \beta}{2.5} \qquad (2)$$

where h is the terrain elevation, β is the local incidence angle and 2.5 is the pixel size in meters. The tangent of β can be obtained dividing the distance from the point to the ground track by the satellite altitude. Figure 2 represents the image and the ground track in UTM map space. Satellite position and approximate image location given in the ancillary data are accurate enough to calculate the value of β, which is not larger than 3° (in that extreme case the relief displacement would be of 1 pixel for a height of 50 meters).

It is important to stress that, unlike with aerial photography, relief displacement is practically independent of terrain height, since satellite altitude is much larger than terrain height variations.
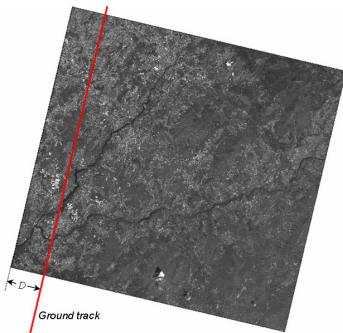

Figure 2. Nadir image and ground track drawn from the ancillary data.

The image coordinates corrected for the height effect will not coincide with the actual position of the point due to the uncertainty in the exterior image orientation, which was used in the processing of 1B2-R images. This effect is essentially a systematic shift, which can be corrected in image space, in the same way as is usually done for Ikonos images (Grodecki and Dial, 2003) and other sensors, by an affine transformation, according to equation (3):

$$\begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix} = \begin{pmatrix} B_1 & B_2 \\ B_3 & B_4 \end{pmatrix} \begin{pmatrix} x'_0 \\ y_0 \end{pmatrix} + \begin{pmatrix} B_5 \\ B_6 \end{pmatrix} \qquad (3)$$

where $(\Delta x, \Delta y)$ is the shift in image space, x'_0, y_0 are the approximate image coordinates. Parameters B_i, which define the transformation, are determined using ground control points. A minimum of 3 points is required but normally more will be used in a least squares adjustment.

2.2 Orientation with ground GCPs

Ground control points were obtained from local map data provided by the Portuguese Geographic Institute (IGP). For planimetric control, orthophotos with pixel size 0.5 m were used. They were produced for standard map scale 1:5,000 and are expected to have a positional accuracy better than 1 m. Heights were obtained from a DEM associated with map scale 1:10,000, which is expected to have an accuracy of 2 meters (IGP, 2008). Local geoid undulation (55 m) was considered, in order to convert DEM heights, since heights considered in equation (2) are above the reference ellipsoid.

A total of 50 points were identified. Nine of them were considered as GCPs and the remaining 41 were used as independent check points (ICPs). Figure 3 represents the location of the points on the nadir image.
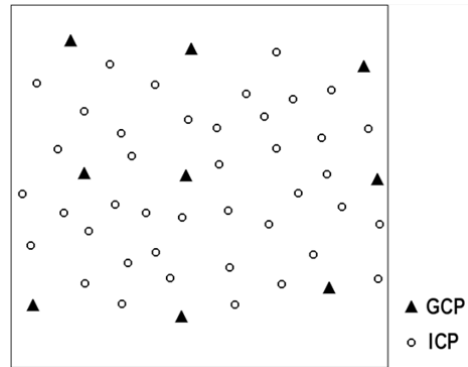

Figure 3. Location of GCPs and ICPs in image space

Applying the expressions described above coefficients of expression (3) were obtained as:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 0.000073 & 0.000048 \\ -0.000551 & 0.000052 \end{pmatrix} \begin{pmatrix} x'_0 \\ y_0 \end{pmatrix} + \begin{pmatrix} -7.4 \\ -27.7 \end{pmatrix}$$

Residuals were calculated for the GCPs, as well as for the 41 ICPs. Table 1 resumes the statistics of the residuals, which were converted to meters, according to the pixel size. Considering the ICPs, a global planimetric accuracy of 2.1 meters was achieved:

$$\sqrt{RMS_x^2 + RMS_y^2} = 2.1m$$

	GCP		ICP	
	Rx (m)	*Ry (m)*	*Rx (m)*	*Ry (m)*
Minimum	-1.2	-1.7	-1.8	-4.2
Maximum	+1.9	1.7	4.1	1.4
RMS	1.0	1.3	1.6	1.5

Table 1. Statistics of residuals found for GCPs and ICPs in the orientation of the nadir image.

3. DETERMINATION OF ELEVATIONS

Forwards (F) and backwards (B) images suffer much larger relief effects than the nadir image. The simplified sensor model wouldn't be as rigorous as for the nadir image. The approach followed in the approximate sensor model consists in register images F and B to the Nadir image space and determine *y* coordinate displacements (designated as parallax), and relate them to heights.

3.1 Registration of Forwards and Backwards images

The registration is done by means of the affine formulas that convert from image to UTM coordinates (also provided for images F and B). A pixel is projected from image F (or B) onto UTM space and from there to image space N. The composition of the two transformations is also an affine transformation.
Between image F (or B) and N, there is essentially the displacement in *y* direction, according to terrain elevation. Image coordinates (F and B) were also measured for the 50 control points. The statistics of the differences are presented in table 2.

	Δx F-N (pixels)	*Δx B-N (pixels)*
Minimum	-5.2	-2.6
Maximum	-2.5	0.9
Mean	-4.0	0.3
Std. Dev.	0.6	0.6

Table 2. Statistics of differences between image coordinates of tie-points between images F and N and B and N.

There was a small systematic shift (4 pixels) between images F and N. This corresponds to a need of a relative orientation, which in approximate terms can be seen as the shift in *x* coordinate. The *y* displacement is the essential parallax value that will be used for height determination.
The difference between images F and B was used, since it is more sensible to height. For the 50 control points parallaxes reached 455 pixels for the highest point (h=1137 m).
The relation between parallax and height needs to be calibrated. Empirically it could be verified that a linear relation fits very well the 50 control points measured, as it can be seen in the graphic plot of figure 4.
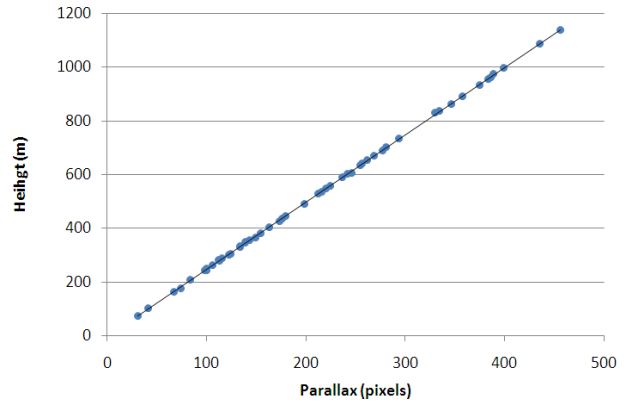

Figure 4. Graphical representation of height versus parallax for the 50 control points used

The main component of this relation can be calculated approximately from the knowledge of approximate pointing angles of the forward and backwards sensors, which in the case of the present image were 26.4 and 26.8 degrees. Being the relief displacement effect given by the tangent of this angle we can obtain an approximate relation of:

$$h = \frac{2.5 \times p_y}{\tan(26.8°) + \tan(26.4°)} = 2.496 \times p_y \tag{4}$$

Plotting now the heights removing this prediction we can still see a remaining linear trend due to the inaccuracy of this prediction (Figure 5). There is also an offset due to the small errors in exterior orientation.
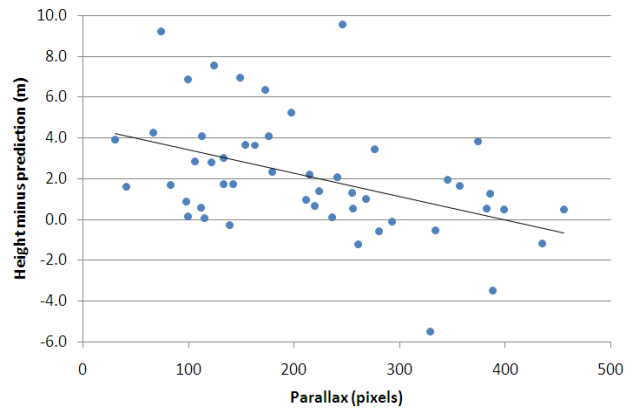

Figure 5. Graphical plot of height (removing initial prediction) versus parallax for the 50 control points used

The linear relation was determined with the 9 GCPs and verified with the remaining 41 ICPs. Table 3 represents the statistics of the residuals in height for the GCPs and the ICPs.

	Rh (m) GCPs	*Rh (m) ICPs*
Minimum	-5.7	-3.0
Maximum	+4.5	+8.3
RMS	2.8	2.6

Table 3. Statistics of residuals in height found for GCPs and ICPs in calibration of height-parallax relation.

4. DISCUSSION AND CONCLUSIONS

This orientation model was applied with another image of the same area, for which very similar results were obtained. However, additional tests with images of different locations and different epochs should be done, for a more secure validation of this empirical model.

Results obtained in this study are worse, as expected, than others referred by several authors, using accurate sensor models. However, a very good accuracy, within the image resolution, was still obtained by this method. Positional standards for 1:25,000 scale, or even larger, are clearly met.

This methodology may be of interest for many users that have 1B2 images and no other specialized software for a proper photogrammetric treatment of PRISM images.

There is always a need of GCPs, which in many remote areas my not be available. Anyway this methodology can also be used replacing GCPs by a control surface (for example the SRTM DEM), in a DEM to DEM matching (Gonçalves, 2008).

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