DEM and orthoimage generation from ASTER L1B images for remote areas

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ABSTRACT: In isolated areas with difficult accessibility, like the Yanachaga-Chemillen National Park in the highest forests of Peru, Digital elevation models at medium scales are necessary as a cartographic input to carry out research on its valuable resources. The stereo restitution capabilities from the Aster sensor could overcome this lack of information. A DEM and an orthoimage were produced for the area using Aster L1B images. Absolute orientation of the model was achieved using control points obtained from a Landsat image and the corresponding national topographic map. Height values were calculated applying a conversion formula that considers the scale distortion on parallaxes generated by the sensor and the height differences were adjusted using signal points identified in the topographic map. Two methodologies for parallax measurements were tested, obtaining the same accuracy with both: a relative orientation with stereoscope and the measurement with parallax bar were equivalent to measurements with photogrammetric software after epipolar resampling, using matching points. To compare the two methodologies the same 7 control points were used and the accuracy for the absolute orientation was evaluated. Finally the model was improved with the software using 11 control points. The results show that an RMSExy = 10 m and an RMSEz = 28 m could be reached combining the proper alignment of Aster L1B images and the better geo-location geometry of Landsat images and topomaps for the provision of control points. The obtained products were suitable enough to complete some of the missing data in the national map at scale 1:100,000.

1 INTRODUCTION

On mountainous areas, like the central Andes in Peru, there is still some information missing in topographic maps. The isolation and extreme conditions of cloud coverage represent difficulties for the collection of good airborne images, therefore portions of the maps appear to be blank. That is the case for the area of the Yanachaga-Chemillen National Park in the central forest of Peru, which does not appear on the corresponding national topographic map.

The use of satellite images with stereo capabilities could overcome this problem. Terra is one of these recent satellites that provide stereo images through its Aster sensor, producing a nadir and a backward view along the tracking line, with a hundred percent of overlapping and a B/H ratio of 0.6.

Earlier works on assessment of vertical accuracy for DEM's obtained from ASTER products show that RMSEz values of approximately ±7 to ±15 meters could be yielded [12, 6], if good ground control points are provided and with a rigorous modeling of the platform. For this study area and other remote landscapes, the provision of ground control points represents a serious difficulty, either because its inaccessibility, or simply due to the lack of budget for a data collection campaign on the field.

If the desired elevation data is required for research applications, like distribution of natural resources or geomorphology in a large scale, DEM's could be generated with enough resolution to derive contour lines at 50 m. interval, similar as a 1:100,000 topographic map, without the need of control points taken on ground. To achieve this, reference points need to be collected from reliable sources. Among this, it is often possible to obtain LANDSAT images with a known planimetric precision in the order of 50 m. [14]. It is also possible, in some cases, to obtain reference points from topographic maps appearing in a remote area.

2 OBJECTIVES

The aim is to complete data missing in the national topographic map corresponding to the Yanachaga-Chemillen National Park area, up to a scale of 1:100000, by means of stereo restitution of Aster images; using reference points obtained from LANDSAT images and topo maps. It is also an objective of the research to test different methodologies for measurement of parallax with analytical and digital tools and, finally, to test the accuracy of the methods for the production of DEM and orthoimages.

3 MATERIALS AND METHODS

3.1 *Study area*

The Yanachaga-Chemillén National Park is a protected area situated in the central high forest of Peru. It is worth for a variety of research topics, from vegetation distribution to geological and soil characterization. The high range of elevations made it suitable for the study of vegetation distribution influenced by altitude factor [13].

This area is a natural "harbor" for a rich flora and fauna; nearly 2600 plant species including around 500 orchid's species represents a record of vegetation diversity. This genetic treasure remains from the last glaciations, 11,000 years back to 1.8 million years during the Pleistocene period, when species found refuges in naturally protected areas. This region is a good example of remote areas, where basic data like topographic maps at medium scale, will help to improve the knowledge and management of natural resources endangered by human intervention.

3.2 *Data preparation*

The data available for this site include:

- Aster image L1B registered radiance at the sensor, algorithm version003. Granule AST L1B.003 2007340175, acquired on 2002-06-19. Center: –10.03° Lat, – 75.44° Lon.
- Landsat TM 5 image, with path-row 7-067, taken on 1999-08-05, georeferenced to WGS84.
- Peruvian national topographic map, sheet 21-L, "Pozuzo", georeferenced to PSAD56-Peru datum.

The software package used was Virtuozo 3.2, which has capabilities for stereo restitution, DEM and orthoimage production.

Subsets were selected from the ASTER images for the region of interest, corresponding to the area that appears blank on the topographic map. An approximate quarter of the full ASTER scene (995 km2) was selected from the near-infrared 3N and 3B bands, over the same area. These two images constitute the stereo pair (see Figure 1).

Aster level 1B has radiometric calibration, to reduce banding and striping effects [1], but there are some necessary adjustments in order to optimize the stereo pair processing with the photogrammetric software.

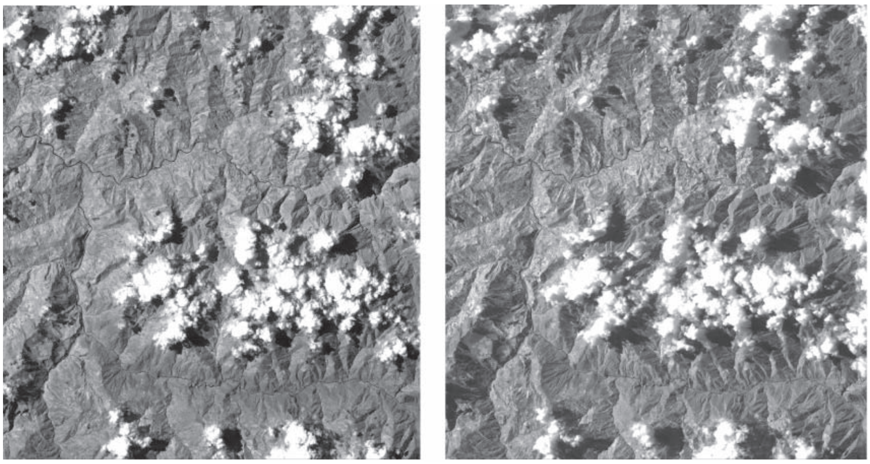

Figure 1. Stereo pair of aster 3N (left) and 3B (right) images.

Contrast balance was applied to one of the images through histogram equalization in order to obtain same levels of contrast and brightness on the pair, and optimize the automatic search of homologue points. Then images are rotated 90 degrees anti-clockwise to adjust the flight line (along track for the case) to the x-axis.

No changes were done regarding geometry; since the L1B level images have geometric correction coefficients already applied, including supplementary data from the instrument and ancillary data from the spacecraft platform [3]. The remaining distortions correspond to the attitude of the sensor not modeled and some vertical scaling anomalies that could be corrected with terrain information.

3.3 *Height information from Aster images*

Since there is not a model built for the Terra platform available on the software, we consider the Aster sensor as a non-metric camera. Then, no interior orientation was considered to derive the stereo model and the workflow started straightforward from the relative orientation.

L1B aster images have geometric corrections for the earth rotation, earth curvature and platform attitude already applied to the images at the processing center [1], this results in an image with an almost constant scale and a proper orientation, that made it already possible to have a stereo view by simply aligning the epipolar images (see Figure 2).

Aster is a digital instrument and images are recorded with a CCD linear array sensor, mounted perpendicular to the platform's motion (push-broom system), therefore the perspective geometry is present only along each scanned line, which results, after first corrections, in an orthographic image only in the direction of flight [10]. The implication of this geometry is that we could not found a principal point for the whole image and a central perspective like in aerial cameras. Instead there is a principal point for each line [4], and they are aligned to the flight line to produce an image frame.

Therefore parallaxes, or the difference in relative positions between two images of points with different height, need to be read between corresponding lines on the two images (line perspective). To calculate height differences (Δh) based on parallax difference (Δp), the same formula as for aerial photographs [9] could be used:

$$\Delta h = \frac{(H - he) \cdot \Delta p}{b} \quad (1)$$

As a difference with aerial photographs where the h/b ratio has an inverse relation with Δp; If we also take in account that the relation between flying height (H) and base (b) remains constant along the whole image after corrections, and that H is equal to the height in the image model (h) multiplied by the scale factor (Sf) between image and ground coordinates ($H = h \cdot Sf$), we could change equation 1 to:

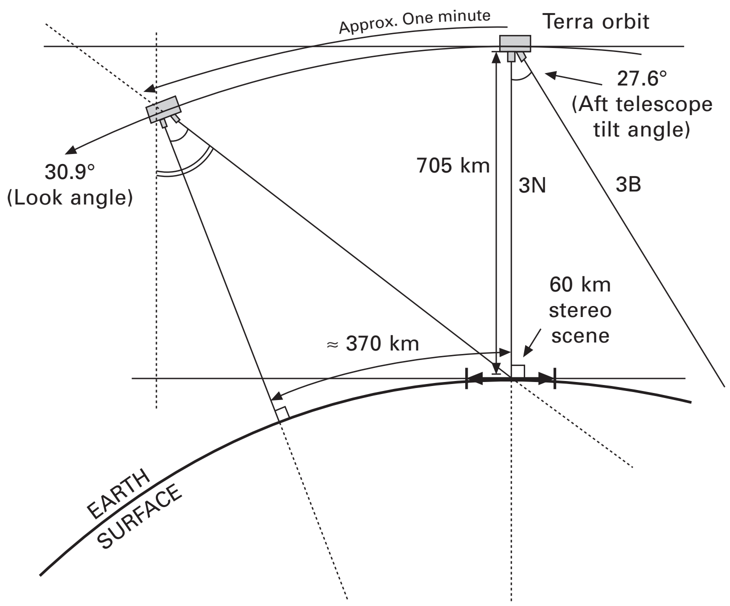

Figure 2. Diagram of the Aster recording geometry [6].

$$\Delta h = \frac{b}{h} \cdot \Delta p \cdot Sf \tag{2}$$

The height to base relation *h*/*b* for digital images, according to Jacobsen [7], is identical to the inverse sum of the tangent of the nadir angles 1/(tan $v1$ + tan $v2$) in the base direction. Since one of the angles has 0°, the relation is reduced to 1/tan $v1$ where $v1$ is the backward angle formed with the base line, which for Aster is 30.96°. From that we obtain the formula to calculate height differences on the model:

$$\Delta h = \tan 30.96° \cdot Sf \tag{3}$$

We should observe that the 30.96° value includes 27.6° for the online tilt of the backward telescope, plus an earth curvature arc of 3.36° formed between the nadiral lines of the satellite at the two recording positions (N and B)(see Figure 2).

3.4 *Control points collection*

As stated on the objectives, the collection of control points in the field was not possible, but instead some control points are able to be collected through the integration of ancillary data from other sensors and sources.

First, control points were identified over the Aster images. The selection was done by visual recognition of distinctive patterns like intersection of rivers or pick of mountains, trying to achieve a proper matching within the range of 1 pixel. The same points are then located in the LANDSAT image to obtain x and y coordinates, and other points were located in the topographic map to obtain height values.

Two signals in the topographic map were identified in the vicinity of the area and the approximate coordinates transformed from the PSAD56 datum to WGS84, to obtain their location on the LANDSAT image. The signal named Cerro Mollepata at 2475 m. height is a mountain pick positively identified, and was used as height pivot reference; the signal called Senal Palmapampa with 850 m. height, is probably a survey signal and was not fully identified, instead a control point was determined by the same contour line using surrounding references. These two points were used to check the range of elevation values.

3.5 *Relative orientation on Aster images*

In this research we compared two methodologies for the measurement of parallaxes on Aster images, regarding the available equipment. On a first instance hard copies of the stereo pair were printed at equal scale and oriented with a Wild ST4 stereoscope. Then using a parallax bar, measurements were done for the selected control points.

As an alternative methodology, values of parallaxes were obtained directly with the software. Virtuozo allows performing operations step by step, and the idea was to measure parallax for the control points in relative units (pixels) after the relative orientation. The detailed procedure is explained below.

3.5.1 *Parallax measurement with stereoscope*

The image prints were aligned with stereoscope to obtain a stereo view and 40 points with distinctive patterns were recognized, including the signals found in the topographic map. From them, 22 points were identified on the LANDSAT image using the ILWIS software and the corresponding x and y coordinates registered. Parallaxes for these 22 points were measured with the parallax bar doing 3 repetitions for each. The parallax differences were calculated between an arbitrary point (for instance the lowest one) and the other points. Using formula 3 the values of height differences were obtained and the signal point in Cerro Mollepata was used as single pivot to adjust heights. In this way a list of 22 full control points with x, y and z coordinates was obtained.

3.5.2 *Parallax measurements with software*

To produce quasi-epipolar images, first a set of 125 matching points was automatically identified by the Virtuozo software on the overlapping portion of the two images; next the position of these points were corrected visually comparing the two images to improve κ, ϕ and ω parameters of the model; then with the epipolar resampling procedure a relative model was built and residuals of y parallaxes returned, which is the equivalent procedure as performed with the stereoscope.

The relative model made it possible to have a stereo view using 3D glasses. Using the stereovision within the software it was possible to locate the selected control points and to measure parallaxes directly from the screen in pixel units, managed by the software [11]. Parallax values were noted for the same 22 points and the parallax difference and height were calculated using formula 3, obtaining a second list of height values.

4 RESULTS

4.1 *Absolute orientation*

To compare the methodologies of parallax measurement on height accuracy, a set of common control points was used. Only 7 out of the list of 22 points were selected as "best" points (the minimum required are 6 points in the software), this limitation was imposed by the lower precision of the floating mark placement using hardcopies on the desktop stereo; while the zooming options in the software allowed for a more precise surface location. The remaining points were used to check the accuracy of the DEM product.

The 7 points were localized on the stereo model produced by the relative orientation and their x, y and z coordinate values were used on the image matching procedure, the DEM generation and the resampled orthoimage product with absolute coordinates. This was done for the height values obtained with the stereoscope and the software. The resulting mean of the roots of the squared errors for the remaining 15 check points shows similar values for the planimetric error and also similar for the altimetry error (see Table 1).

Since accuracy is almost the same for both methodologies, and even slightly better using digital measurements, we opt to improve the model only within the software method using 10 control points for the DEM generation, resulting in an improvement in altimetry up to RMSEz = 28 meters and 10 meters in planimetry.

Table 1. Comparative RMSE of check points (in meters) on DEM's produced with 7 control points measured with analogical and digital methods.

Method	RMSE xy (m)	RMSE z (m)
Analogic	12	39.8
Digital	13	36.8

4.2 *Products*

A DEM with 50 meters resolution was produced with the software, along with an Ortho-image at the same resolution, and exported into a TIFF file. Both images were reoriented to the north and assigned proper coordinates. With the spatial analyst extension on ArcView 3.2, contour lines were created each 200 m. and superposed over the orthoimage layer to produce an orthomap for the area, referenced to WGS84 coordinates (see Figure 3). To show the resulting images in a larger scale, contour lines are presented each 50 m. over a partial area corresponding to the Santa Cruz river (see Figure 4).

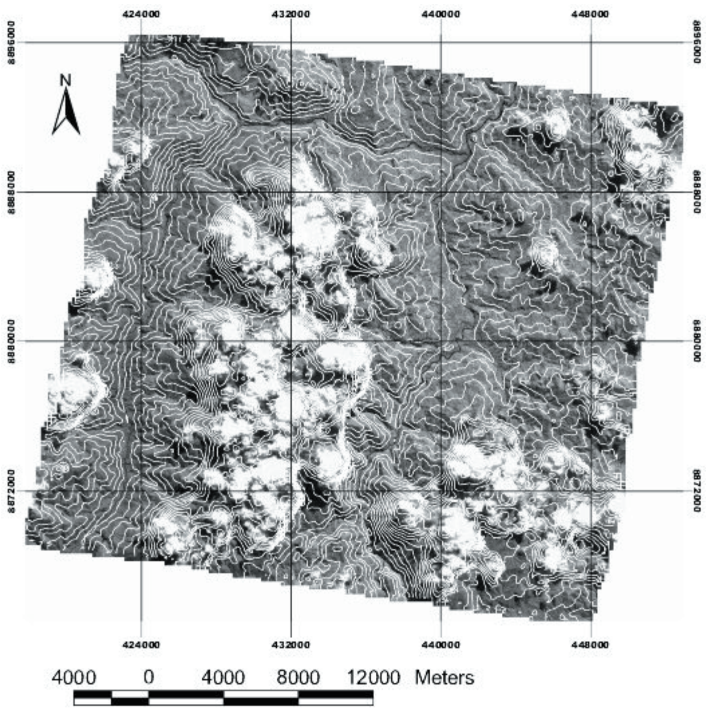

Figure 3. Orthomap for the AOI with contour lines each 200 m.

5 DISCUSSION

In a "relative" way the error obtained in planimetry for the DEM is low, which indicates that the control points had an acceptable precision. That confirms the condition of Landsat images as a good source for control points. One reason for this positive condition is that Landsat provides wide views covering as much as 185 × 185 square km. Thus several fixed points in the scenes are likely to found these results in a better geometric correction and coregistration of the Landsat images with no big image displacements in mountainous areas [9].

Even observed that geo-location is not rigorous on Aster products, due to a limitation on the accuracy to determine the platform position [3], the image pair of bands 3N and 3B on Aster L1B

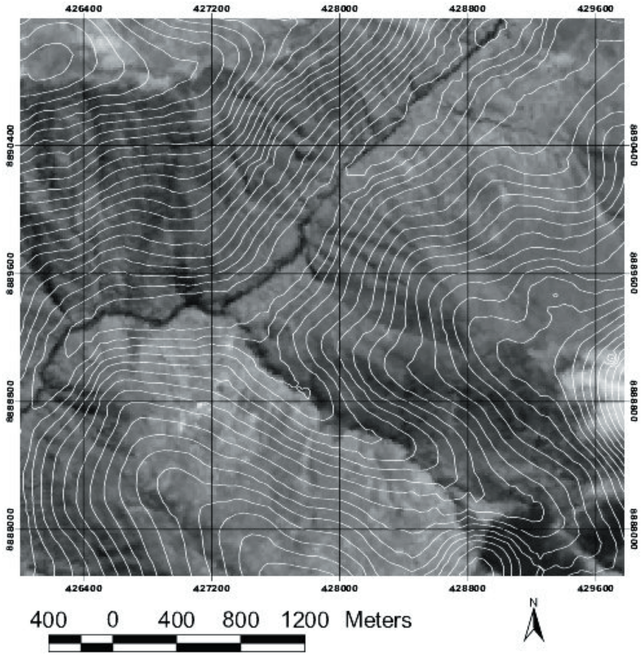

Figure 4. Detail of the Orthomap with contour lines each 50 m.

products is coregistered and then could be oriented without difficulties to obtain epipolar images and to make readings of parallaxes. In this way measurements of height are made independently from planimetry. The same could be done with L1A products after applying the geometric parameters.

The geo-location distortions that are known to be present on the processed images L1B, are more noticeable on mountainous areas, where the differences between the ellipsoid plane and geoid are bigger [2]. On the other hand areas with high differences on relieve usually present very distinctive patterns, which helps to recognize the matching points used for the relative orientation and control points used for the absolute orientation.

Aster L1B is suitable for parallax measurements with a variety of instruments. Analogue instruments could be used, providing the user with human eye accuracy for pattern recognition. Even better and depending on availability, specialized software with stereo viewing capabilities will make the process less time consuming. The orientation done with software showed a good stability, allowing the inclusion of more control points and reducing errors.

The products obtained with the described methodology has an acceptable precision to be included in topographic maps at 1:100000 scale. In planimetry it is possible to reduce the errors within the resolution of the coarse image source, for the case Landsat TM with 30 m. Additional errors in altimetry are due to Aster characteristics and depending on the precision of control points. It is noticeable that the RMSEz for the study area (28 m.) represents 3 times less than the 0.015% of the flying height above ground required as precision for aerial pictures [5] and at the same time remains on less than 1.5% of the total altitude range of the area (approx. 2000 m.).

As could be observed on Image 4, there is still a large area within the park covered by clouds at the center of the image, which must be treated as missing information. Eventually these blank areas could be updated from new images, since it is expected that, during the six-year mission of the Aster along-track experiment, cloud free stereo coverage of 80 % of the Earths land surface will be acquired [8].

CONCLUSIONS

- Landsat images could provide a good support to georeference images with a required accuracy equivalent to 1:100000 map scale.

- Similar accuracy is obtained with analogical and digital methods for parallax measurement. The use of software makes the process easier and faster.
- A DEM for the area of the Yanachaga-Chemillen national Park was produced using 10 control points, yielding a RMSExy = 10 m. and a RMSEz = 28 meters.
- Aster L1B products could be used to obtain elevation data, good enough for natural resource modeling applications.

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