ORTHORECTIFICATION OF PRISMA IMAGES

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ABSTRACT:

Orthorectification is one of the most important satellite imagery pre-processing applications, as it allows to use data, for example, in geographic information systems, making the most of high or medium resolution. Since May 2020, PRISMA (PRecursore IperSpettrale della Missione Applicativa) mission, a project of the Italian Space Agency, has become fully accessible to the community. PRISMA satellite integrates a hyperspectral sensor and a medium-resolution panchromatic sensor. The products are currently available with a declared geolocation accuracy of 200 m, which ASI plans to increase to half pixel in the near future by introducing geometric treatment of the images with Ground Control Points (GCPs). However, the orthorectification of PRISMA images is not a proven and validated procedure, due to the uncertainty of satellite orbital and internal orientation data provided in the metadata file and to the lack of contributions on the subject in literature. In the present work, our contribution on possible strategies for the geometric treatment of PRISMA images is shown. The results obtained by applying the Rational Polynomial Coefficients (RPC) provided with some panchromatic images show coarse rototranslations. For this reason, a procedure was developed to restore conformity between RPCs and the panchromatic image. The best results in terms of accuracy were obtained with the rational polynomials using RPF approach, achieving residuals calculated on the Check Points (CP) in the order of one pixel, better than those supposed by ASI using GCPs. Probably even better results could be obtained with more rigorous information on RPCs or orbital and orientation parameters.

1. INTRODUCTION

The Italian Space Agency (ASI) mission PRISMA is one of the latest innovations in the area of remote sensing, characterized by an innovative hyperspectral technology. The launch of the satellite took place on 22 March 2019, from the Kourou European spaceport in French Guiana, and starting from May 2020 it reached operational conditions, becoming available to the scientific, institutional, industrial, Italian and international communities. The aim of the mission is to encourage experimentation with hyperspectral data. In fact, ASI has chosen to make this data available with a user licence for the benefit of the scientific community and national and international institutional users. The application opportunities of PRISMA data are unlimited, the hyperspectral sensor (Ground Samplig Distance 30 m) is integrated with a panchromatic sensor, 5 m spatial resolution, that improves the observation capabilities based on the recognition of geometric characteristics of the scene. The main purpose of this paper is to carry out a study of the possible strategies for the geometric treatment of PRISMA images, a topic still poorly investigated in literature probably due to the recent availability of PRISMA products. Considering the innovativeness of the mission, the studies conducted so far have focused on possible hyperspectral applications, using already georeferenced data, however it is necessary to verify the accuracy of geolocation (Busetto et al., 2020). In fact, ASI currently declares 200 m geolocation accuracy (ASI, 2017) of the hyperspectral and panchromatic products, and it plans to improve it to half pixel in the near future, by introducing a geometric treatment of the images with GCPs. However, it must be considered that satellite images are affected by distortions due to various factors. The distortions must be corrected returning a geometrically correct and accurate representation of images also from the point of view of geographical positioning. Therefore, it is necessary to perform on satellite images a pre-processing procedure known as image orientation and, based on this, the orthorectification. In the present work, an orthorectification procedure of the PRISMA panchromatic product is presented, which has made it possible to achieve results with accuracy in the order of one pixel, better than those expected by ASI with GCPs.

1.1 The PRISMA mission

PRISMA satellite has been planned to be on a sun-synchronous orbit at an altitude of about 620 kilometres and to have an orbit with 97.851° of inclination (Loizzo et al., 2016).
The hyperspectral payload is an electro-optical instrument based on a pushbroom scanning technique and consisting of a high spectral resolution imaging spectrometer in the spectral range 0.4-2.5 µm, optically integrated with a medium resolution panchromatic camera in the spectral range 0.4-0.7 µm. The payload acquires panchromatic and hyperspectral images of the Earth's surface with a swath width of 30 km and a length of up to 1800 km, in along-track direction and at a fixed off-nadir angle. It also has the agility to acquire data up to +/-14.7° off-nadir and the daily capability to acquire up to 200,000 km^2 of imagery over the area of interest (180° W÷180° E and 70° S÷70° N). The raw data are 1000 x 1000 hyperspectral images and 6000 x 6000 temporally co-registered panchromatic images, corresponding to an area of 30 km × 30 km on the ground. The products available to end users are organised in a hierarchy of levels, according to which different co-products are offered:

- Level 1: Top-of-Atmosphere spectral radiance, radiometrically-corrected and calibrated
    - Cloud cover, Sun-glint and Land Classification masks

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- Level 2B: Bottom-of-Atmosphere spectral radiance, atmospherically corrected, the geolocation coefficients are available in the metadata, but not applied
- Level 2C: like 2B products, but they also provide:
    - Water vapour, aerosols and cloud characterization
- Level 2D: Bottom-of-Atmosphere spectral reflectance, atmospherically corrected, the geolocation coefficients are appended and applied. It is the geocoded version of the level 2C products.

2. PROCESSING CHAIN

2.1 Materials

The geometric treatment was tested on two PRISMA panchromatic images, level 2C products, one of the area of Rome and the other on the Ischia island (south of Italy, in the Tyrrhenian sea). This choice was justified by the different topographical characteristics. In particular, the Ischia Island is characterised by the presence of very rapid variations in altitude from the coast to the summit of the volcanic mountain called "Monte Epomeo" (789 m orthometric height), that represent an interesting case given the importance of altimetric information in orthorectification. For this first experimentation, an attempt was made to investigate as many algorithms as possible in order to obtain a broader panorama of the geometric treatment. Therefore, both the open-source software QGis, which supports the OTB and GDAL libraries, and the commercial software OrthoEngine, were used.

Digital elevation models with a spatial resolution compatible with the average resolution of panchromatic images were used in the orthorectification procedure. For Rome image, the DEM TINITALY/01 provided by INGV (Tarquini et al. 2007) was used as a 10 m grid of cell size while for Ischia image a DEM in orthometric elevations was created starting from official cartography in scale 1:2000. For the estimation and control of the geometric model, 65 ground points (50 GCP and 15 CP) were used for each image. On both sites, points from large-scale mapping and GNSS surveys were available both with higher accuracy than the pixel size.

2.2 Exporting the panchromatic product

PRISMA products are distributed in HDF format, so it is necessary to export them in more commonly used formats, such as TIFF. The panchromatic product of L2C level, not geocoded, was exported using ENVI software version 5.5.3 which is able to read the PRISMA data distribution format. During exportation phase, it is important to check that the raster is not geocoded to avoid the return of altered data that are not congruent with the Geocoding Model parameters provided. To verify the absence of geocoding, the exported image can be imported into any GIS software to check that the graphic restitution of the raster corresponds to its internal coordinate reference system (i.e. the coordinates of the top-left corner must be 0, 0).

Opening the HDF file, ENVI initially displays the VNIR raster only. The Data Manager opens three raster files, each covering the same geographic area but providing different spectral coverage and spatial resolutions:

- VNIR 30 m resolution (400-1010 nm, 66 bands)
- SWIR 30 m resolution (920-2500 nm, 173 bands)
- Panchromatic 5 m resolution

Then, the panchromatic product can be selected and exported in TIFF format. The information regarding the Geocoding model (ASI, 2020) is contained in the HDF file, but is not attached to the exported TIFF product. For this reason, they have been attached using a text file compatible with the RPC00B format. In fact, as reported in the documentation, the geocoding model adopted for L2 products is that of Rational Polynomial Coefficients: RPC00B - Rapid Positioning Capability, as defined in the National Imagery and Mapping Agency standard (NIMA, 2000).

2.3 Orthorectification

The geometric treatment of the image initially involves the choice of a suitable orthorectification model to eliminate the image distortions. Orthorectification is often the first and most important step in obtaining accurate results from the various applications of satellite imagery (Baiocchi et al. 2010, Zollini et al. 2020). Orthorectification methods can be divided into two categories: physically based models such as the rigorous model, and empirical models such as polynomial rational functions. The rigorous model is based, according to the classic photogrammetric approach, on the reconstruction of the collinearity equations that relate the image space to the object space (Kraus, 1993). These models require knowledge of the parameters which describe the sensor and the acquisition geometry, such as the position and attitude parameters of the platform, as well as the optical-geometric parameters of internal calibration of the sensor (Toutin, 2011).

This supporting data is not provided together with PRISMA products, and the recent release has not yet allowed to carry out in-depth studies on this sensor. For this reason, the few optical geometric data available in the literature (Loizzo et al., 2016) on this specific satellite have produced inconsistent results in a preliminary test, which has therefore not been further investigated.

On the other hand, rational polynomial functions (RPFs) do not consider the geometric process of image acquisition, they represent an approximation of the rigorous method. Since they do not refer to a particular type of sensor-platform pair, they can be applied generically to any satellite image. The RPFs express the row and column values as a function of latitude, longitude, and ellipsoidal height, using a series of polynomial coefficients, as follows:

$$
\begin{aligned}
r_n &= \frac{\sum_{i=1}^{20} LINE\_NUM\_COEFF_i \cdot \rho_i(P,L,H)}{\sum_{i=1}^{20} LINE\_DEN\_COEFF_i \cdot \rho_i(P,L,H)} \\
c_n &= \frac{\sum_{i=1}^{20} \mathrm{SAMP}\_NUM\_COEFF_i \cdot \rho_i(P,L,H)}{\sum_{i=1}^{20} SAMP\_DEN\_COEFF_i \cdot \rho_i(P,L,H)}
\end{aligned}
\qquad (1)
$$

Where r_n, c_n = image coordinates
P, L, H = latitude, longitude, ellipsoid height

Every rational polynomial has the following form:

$$
\begin{aligned}
\sum_{i=1}^{20} C_i \cdot \rho_i(P,L,H) = {} & C_1 + C_2L + C_3P + C_4H + C_5LP \\
& + C_6L + C_7PH + C_8L^2 + C_9P^2 \\
& + C_{10}H^2 + C_{11}PLH + C_{12}L^3 \\
& + C_{13}LP^2 + C_{14}LH^2 + C_{15}L^2P \\
& + C_{16}P^3 + C_{17}PH^2 + C_{18}L^2H \\
& + C_{19}P^2H + C_{20}H^3
\end{aligned}
\qquad (2)
$$

Rational polynomial functions are distinguished into RPFs based on ground control points (RPF approach) and RPFs calculated from coefficients provided with the satellite images themselves (RPF with RPC approach). The difference is that in the former case the coefficients are estimated by least squares from a set of GCPs, while in the latter case they are provided with the image to be processed. PRISMA images are supplied with the Geocoding Model information, consisting of the rational polynomial coefficients (RPCs), contained in the original HDF format file. Currently, Orfeo Toolbox (OTB) has only been validated with the rational polynomial function method (Baiocchi et al., 2020), while OrthoEngine supports all three orthorectification methods. As mentioned above, the Geocoding Model information has been manually transcribed in the RPC00B format, then, before the orthorectification procedure, it is necessary to verify that all software read the Geocoding model correctly using the otbgui_ReadImageInfo application in OTB and gdalinfo from the gdal library.

The orthorectification process using the RPF method with RPCs has been subsequently performed using OrthoEngine, the open-source applications otbgui_OrthoRectification and gdalwap, obtaining with all software an image rotated approximately 90° in the clockwise direction as output. The reasons for this inconsistency are still unclear as the RPCs are claimed to conform to the NIMA standard (NIMA, 2000).

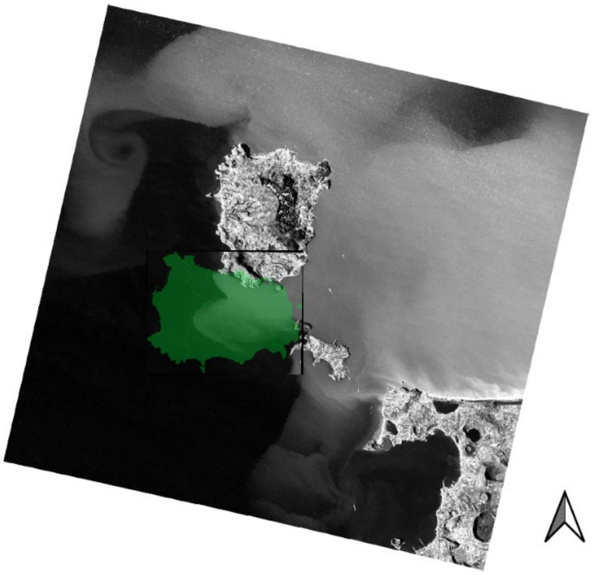

Figure 1. OrthoEngine "orthorectified" output (the raster is cropped at the DEM of the island of Ischia), superimposed on the OTB "orthorectified" output. Note that both outputs are rotated by 90° with respect to the correct position of the island of Ischia, represented in green. The island is approximately 9 km wide

Because of these problems, the method of rational polynomial functions (RPF) has been also tested, computing the coefficients by means of least squares estimation from a series of GCPs distributed homogeneously over the image. RPFs are the least correct method from a photogrammetric point of view (Toutin, 2011) and furthermore, this method has non-negligible disadvantages such as the need of a high number of GCPs, excessive sensitivity with respect to the distribution of GCPs, non-robustness against outliers and the presence of possible strong distortions in areas far from the GCPs.

In order to estimate the 78 coefficients required for the third-degree polynomials, the minimum number of points to collimate is 39 (two equations are written for each GCP). However, for the calculation to be carried out under conditions of redundancy, it is necessary to consider 20% more GCPs. For this reason, 50 points were collimated and used for the estimation of the geometric model (GCPs), and another 15 for the validation of the model (CPs). Note the importance of GCPs for processing purposes: they must be easily "recognisable" both on the image and on the ground, the accuracy of their coordinates influences the correspondence established. Therefore, the points must be homogeneously distributed on the image, otherwise the resulting model may present deformations in areas far from the GCPs.

2.4 Results

Considering the large number of GCPs required and the average resolution of the image to be processed, the GCPs were identified from vectorial cartography. For the image of Rome, vectorial cartography in scale 1:5000 provided by the Lazio Region website (Regione Lazio, 2021) was used (declared +/- 1 m horizontal accuracy, +/- 2m vertical accuracy). While for the island of Ischia the vectorial cartography in scale 1:2000 provided by the Metropolitan City of Naples was used (declared +/- 40 cm horizontal accuracy, +/- 70 cm vertical accuracy).

Points surveyed with GNSS receivers were available from previous research on higher resolution imagery, but they couldn't be used because the resolution of PRISMA products did not allow the correct identification on the image. The results of the application of the RPF method without RPC are acceptable at a first visual verification, by overlaying the orthorectified panchromatic product and vectorial cartography.

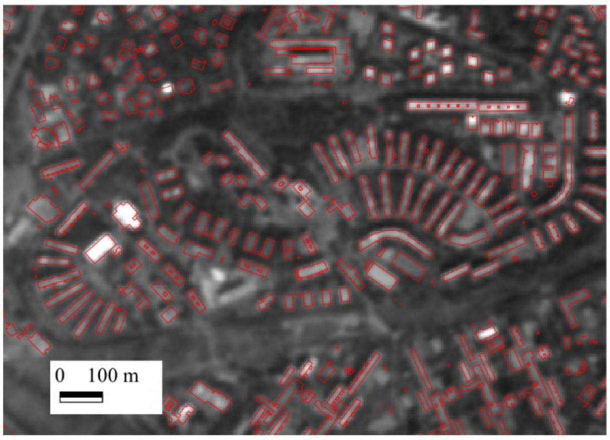

Figure 2. Portion of orthorectified panchromatic image and superimposed cartography at scale 1:5000 (Rome)

The precision of the planimetric positioning was calculated from the residuals on the GCPs, while the accuracy was calculated on the CPs.

	X RMS [m]	Y RMS [m]
GCPs	2.77	3.09
CPs	3.82	4.40

Table 1. Residuals obtained with OrthoEngine software for the image of Rome

	X RMS [m]	Y RMS [m]
GCPs	6.11	4.76
CPs	5.15	6.41

Table 2. Residuals obtained with OrthoEngine software for the image of island of Ischia

The results obtained with the RPF method confirm the local validity of the method, presenting lower precision values compared to the accuracy calculated on the CPs. The image of

Ischia presents overall higher residual values, although in the order of one pixel. The reason for this could be that the collimation of GCPs and CPs was more difficult due to the topographic characteristics of the island, which also influenced the development of the urban texture and the type of buildings. In addition to this collimation error, it must be remembered that the points were identified on vectorial cartography at large scale with the accuracy already illustrated. However, in spite of these subtle differences, the RPF approach produced residuals on the CPs in the order of the pixel, which is better than what ASI assumes using GCPs.

3. CONCLUSIONS

The present paper deals with the geometric treatment of the images acquired by PRISMA satellite platform launched and managed by the Italian Space Agency. PRISMA satellite is very recent, probably for this reason there is practically no contribution in the literature concerning the geometric treatment of the satellite itself. For this reason, it was decided to experiment different orientation strategies known in the literature with the aim to verify which ones could be the most efficient; all tests were conducted considering the major software used for the geometric treatment of satellite images. Usually, RPF with RPC and RPF approaches are used more because they do not require photogrammetric algorithms and geometric-orbit sensor information. The RPF with RPC method has given erroneous results with coarse rototranslations. The cause of this discrepancy is still under investigation as PRISMA's RPCs are claimed to comply with the NIMA (National Imagery and Mapping Agency) standard. To verify this, we recalculated the RPC parameters in NIMA standard using a large number of GCPs and in this case the image was orthorectified correctly obtaining low residuals on the CPs.

The RPF approach is usually avoided because it requires many GCPs and is not statistically robust. However, it should be noted that, given the low resolution of the image, GCPs can advantageously be acquired from vectorial cartography in scale 1:5000/1:10000, which is now available over the whole national territory. Therefore, with this specific type of image, there is no need to acquire coordinates through expensive survey campaigns with differential GPS/GNSS receivers and therefore the number of GCPs to be used is not really a critical factor.

In addition, the validation of the model estimated with the RPF approach shows that the residuals on the CPs are in the order of one pixel and therefore better than those expected by ASI with the use of GCPs. Probably with more rigorous information on RPCs or on orbital and orientation parameters even better results could be obtained, in fact previous experiments on similar satellite platforms have shown that it is possible to achieve even half a pixel of accuracy, so we believe there is certainly further room for improvement (Baiocchi et al. 2020).

Currently, our strategy is the most accurate and efficient and can give results compatible with 1:50000 at the map production stage or 1:25000 at the map update stage.

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