GEOMETRIC POTENTIAL OF PLÉIADES 1A SATELLITE IMAGERY

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Abstract

In this paper, the geometrical characteristics of Pléiades 1A satellite imagery (both single and stereo) are analysed. At first the process of digital surface model (DSM) extraction from a Pléiades 1A stereo pair is described and analysed. After that geometric an accuracy of imagery, orthorectified using the extracted DSM and using the SRTM (Shuttle radar topographic mission) was analysed. The Pléiades 1A stereo pair was acquired on October 22, 2012 from the same orbital pass over an urban zone (Kiev, Ukraine). The study area is heterogeneous: there are both built-up and flat areas. The iImage orientation, DSM extraction and orthorectified images generation were performed using the PCI Geomatica 2013 software. The results showed that a strong, positive correlation between reference-derived elevations and DSM-derived elevations can be observed, and the orthorectified image accuracy, generated using that DSM, approximately equal to 1 m can be achieved using a bias compensation sensor model. Different sensor models were used for orthorectification using the SRTM. In this case, the geometric accuracy is a function of a chosen sensor model and a number of ground control points (GCP).

Key words: Pléiades 1A, digital surface model, SRTM, orthorectified image, bias compensation model.

1 INTRODUCTION

Modern, very high resolution satellites introduce wide possibilities for the large-scale topographic mapping and accurate 3D modelling of topographic features.

DSMs extracted from stereo satellite imagery models both terrain and topographic objects (buildings, trees etc.). Those DSMs are widely used in different applications: vertical planning, water flow modelling, 3D feature extraction, mass movement, etc. They are also used in photogrammetry for orthorectification and allow for very accurate orthorectified images.

Orthorectified images, generated using very high resolution satellite imagery, have a pixel and sub-pixel geometric accuracy. Therefore, many authors consider them as an alternative or even a substitute to traditional methods for creating large-scale topographic layouts [1,2].

For quite a long time, terrestrial surveying and aerial surveying were the only ways to generate DSMs and large-scale topographic layouts. But with the development of commercial, very high resolution satellites, stereo pairs have increasingly been used for the DSM extraction and large-scale topographic layouts generation. The main advantages of this approach are: lower costs, time-saving, and the possibility of surveying hard-to-reach places (for example, mountainous regions).

Pléiades 1A is one of the latest commercial, very high resolution satellites. Pléiades 1A was launched on December 16, 2011 from the Kourou spaceport (French Guiana) by means of a "Soyuz" (Russia) launch vehicle. The satellite launch was performed by the French company "Astrium EADS" and the French National Space Agency. The acquisition of very high resolution imagery during at least five years is the main task of Pléiades 1A. A ground sample distance (GSD) of images is 70 cm for a panchromatic band and 2.8 m for a multispectral band. But for commercial users, the imagery is delivered after resampling to 50 cm for the panchromatic band and to 2 m for the multispectral band, respectively [3]. Such characteristics allow discussions about a high accuracy DSM extraction.

On June 30, 2014, SPOT 7 was launched, which, along with Pléiades 1A, Pléiades 1B and SPOT 6, forms a constellation and covers almost all of the Earth with a revisit time of 24 hours [4].

A couple of sensor models may be used for satellite stereo pair processing: physical and mathematical models. The physical (or rigorous) model describes dependence between image coordinates and ground coordinates by collinearity equations where each parameter has a physical sense [5]. The mathematical (or generalized) model is an approximation of the physical model where the dependence between image coordinates and ground coordinates is described by RPCs (rational polynomial coefficients) that are usually delivered by a

data provider or can be calculated manually using GCPs [6]. The preference is given to the second approach, as it gives more reliable and accurate results [7].

In the paper [8], the geometric accuracy of a single Pléiades 1A image for the territory of Zonguldak (Turkey) was analysed. The authors recommend using a bias compensation model in order to remove systematic errors of the supplied RPCs, thus achieving a highest geometric accuracy.

In the paper [9], for the GeoEye-1 imagery, an RPC0 (rational polynomial coefficients refined by a zero order polynomial adjustment) model with only one GCP was used to achieve a sub-pixel accuracy. The authors concluded that the main errors of RPCs are systematic and thus can be easily removed by a simple bias compensation model which can be described using one point (two unknown parameters). Similar conclusions are given in other researches [10-13].

There are two main aims of this paper: to assess the accuracy of the DSM extracted from the Pléiades 1A stereo pair for an urban area (territory of the city of Kiev, Ukraine); to assess geometric characteristics of imagery, orthorectified using the extracted DSM and using the SRTM.

2   STUDY AREA AND INPUT DATA

The study area is located in the western part of the city of Kiev (Ukraine) and its suburbs (Fig. 1). The territory is heterogeneous: there are both built-up and flat areas. The mean elevation of the area is 165 m, ranging from 90 m to 240 m above the Baltic Sea level. The territory has a square shape with an area of approximately 411 km^2 and a side length of 20.27 km.
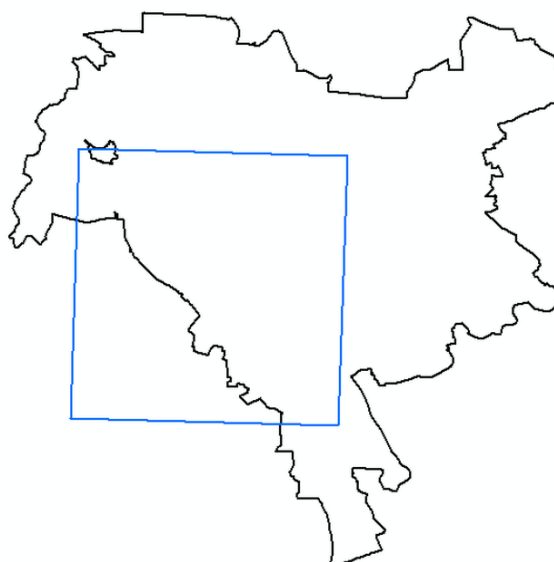

Fig. 1 Location of the Study Area (blue colour)

2.1 Pléiades 1A stereo pair

A stereo pair of panchromatic and multispectral images with 100% overlap was used in this research. The images were acquired on October 22, 2012 from the same orbital pass with the GSD equal to 0.5 m. The metadata about the stereo pair is shown in Tab. 1. A base to height ratio (B/H) is 0.4, a convergence angle – 23°. According to the conclusions of the work [14], such a convergence angle is not ideal to achieve high vertical accuracy of a stereo pair (the highest possible vertical accuracy is achieved by increasing the convergence angle up to 60°).

Tab. 1 Metadata on Stereo Pair

Image	Forward	Backward
Format	JPEG2000	JPEG2000
Processing level	Primary	Primary
Colour depth	12 bit	12 bit
Acquisition date	22/10/2012 09:08:52	22/10/2012 09:09:29
Cloud cover	0%	0%
Image size (row × column)	40520×40000	40067×39945
Pixel size: panchromatic channel multispectral channel	0,5 m 2 m	0,5 m 2 m
Sun angle azimuth	170°22′6,1″	170°38′40,2″
Sun angle elevation	28°04′6,8″	28°05′46,7″
Coordinate system	WGS-84	WGS-84

The primary product is the processing level closest to the natural image geometry acquired by the sensor. This product restores perfect collection conditions: the sensor is placed in rectilinear geometry and the image is clear of all radiometric distortions. The RPCs supplied with a stereo pair are most approximated to the physical model of the sensor. The declared vertical accuracy of the stereo pair (absolute error) if B/H = 0.6 is 1 m and if B/H = 0.25 then 3 m.

2.2 GCP and ICP

Coordinates of five GCPs were measured by geodetic-class GPS receivers in absolute mode with accuracy of 2 cm in autumn 2012. The points are located in open areas at different elevations. They are placed in north-eastern part of the study area and are well identified in images.

56 points from the vector topographic layout, 1:2,000 scale, with a vertical interval of 1 m were used as ICPs (independent check points) for the extracted DSM accuracy assessment. The accuracy of ICP elevations is equal to ⅓ of the vertical interval or 33 cm. The elevations of the points from the topographic layout can be used as reference elevations, taking into account the declared vertical accuracy of 1 m and the fact that the reference elevations must be at least three times more accurate than the product specification. The topographic layout was created in 2012 using scanned paper plans, 1:2,000 scale, and was updated by means of satellite imagery and terrestrial surveying.

16 points from the paper topographic layout, 1:500 scale, were used as ICPs for the accuracy assessment of orthorectified images. The accuracy of the ICP coordinates is to within 15 cm so they also can be used as a reference. The topographic layout was created in 2000, so only steadfast contours that haven't been changed since that time were used.

The distribution of the GCPs and the ICPs is shown in Fig. 2.
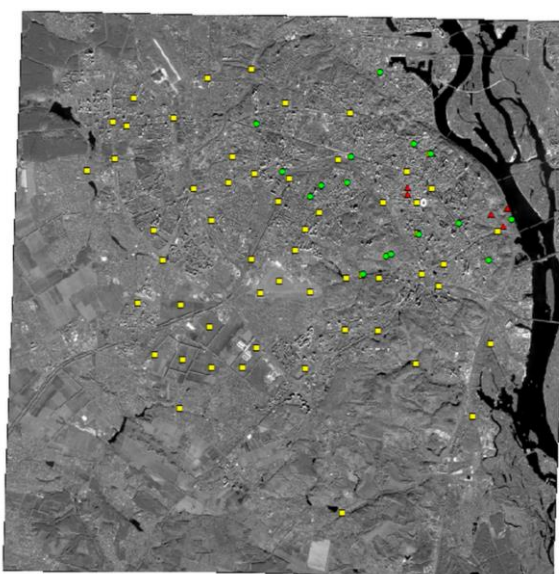

Fig. 2 Distribution of GCPs and ICPs: Red Triangles – GCPs; Yellow Squares – ICPs from Topographic Layout, 1:2,000 scale; Green Circles – ICPs from Topographic Layout, 1:500 scale

2.3 Sensor model

A bias compensation RCP0 model with five GCPs was used in this research for the DSM extraction and orthorectified images generation. Only one GCP is used in this model for the RPC-refinement: two bias parameters are computed in the north-south and east-west directions, and redundant points are used for the adjustment of parameters by a least-square algorithm. The model RPC0 is described by the following formulas [15]:

$$l = l_N + a_0 \tag{1}$$

$$s = s_N + b_0 \tag{2}$$

$$l_N = \frac{P_1(\varphi_N, \lambda_N, H_N)}{P_2(\varphi_N, \lambda_N, H_N)} \quad s_N = \frac{P_3(\varphi_N, \lambda_N, H_N)}{P_4(\varphi_N, \lambda_N, H_N)} \tag{3}$$

where:

l_N, s_N – initial normalized pixel coordinates on image;

l, s – corrected pixel coordinates;

a_0, b_0 – bias parameters;

P_1, P_2, P_3, P_4 – 3rd order polynomials;

φ_N, λ_N, H_N – normalized ground coordinates with respect to a certain ellipsoid (usually WGS-84).

The photogrammetric software used in this research was OrthoEngine from PCI Geomatica 2013 which supports the chosen RPC0 model.

3 METHODOLOGY

3.1 DSM extraction

OrthoEngine was used for both the stereo pair orientation and the DSM extraction. Tie points were extracted automatically using correlation algorithms for searching identical points in overlapping images. Matching was done by comparing the statistical data about brightness and contrast collected in a window of a specified size. The pixel size of the extracted DSM is 2 m (Fig. 3). This size was chosen with consideration to the optimal ratio between the size of the output file and the time of the procedure. A high resolution DSM and a hilly terrain were selected in the OrthoEngine parameters.

According to recommendations [16], a high planimetric and vertical accuracy of a GCP (sub-pixel level) is a key issue for a high accuracy DSM extraction. In our case, for five GCPs, mean RMSEx was 0.24 m and mean RMSEy was 0.26 m. RMSEx and RMSEy for separate points did not exceed 0.44 m and 0.38 m, respectively.
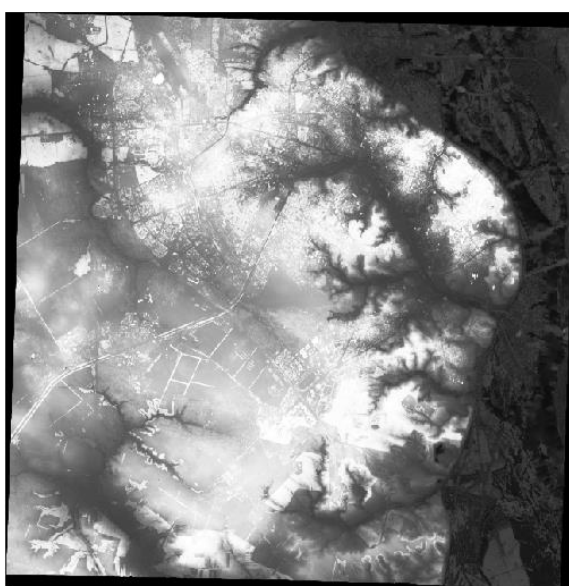

Fig. 3 DSM extracted from Pléiades 1A Stereo Pair

3.2 Orthorectified images creation

At first, the panchromatic channel and the extracted DTM (that was previously automatically converted from the DSM using Geomatica 2013 tools) were used for orthorectification. RPC0 with one GCP was the chosen model.

After that, the SRTM and RPCs were used for orthorectification with a different number of GCPs (from 0 to 5). The possibility of using the SRTM for very high resolution satellite imagery orthorectification was justified in research [17]. RPC0 was the chosen model.

The pixel size of orthorectified images is 50 cm. In order to get colour images, the multispectral channel was orthorectified with the same method and pansharpening was done.

4 RESULTS OF DSM ACCURACY ASSESSMENT

The accuracy assessment of the extracted DSM was carried out using 56 control points from the vector topographic layout, 1:2,000 scale. Well-known parameters were chosen as accuracy indicators.

The results are shown in Tab. 2.

Tab. 2 Results of DSM accuracy assessment

Parameter	Value, m
Mean absolute error	1,639
Root mean square error	2,079
Minimum elevation difference	0,010
Maximum elevation difference	6,035
LE90	3,421
LE95	4,076

The results show that the RMSE of ellipsoidal heights for the extracted DSM is approximately equal to its pixel size (2 m). The mean absolute error regarding B/H does not exceed the value from product specification. A visual inspection of the DSM confirms its high quality (Fig. 4). The highest errors were found in the areas of sparse green plantations and small-feature areas (e.g. sheds) that are not represented in the reference topographic layout.
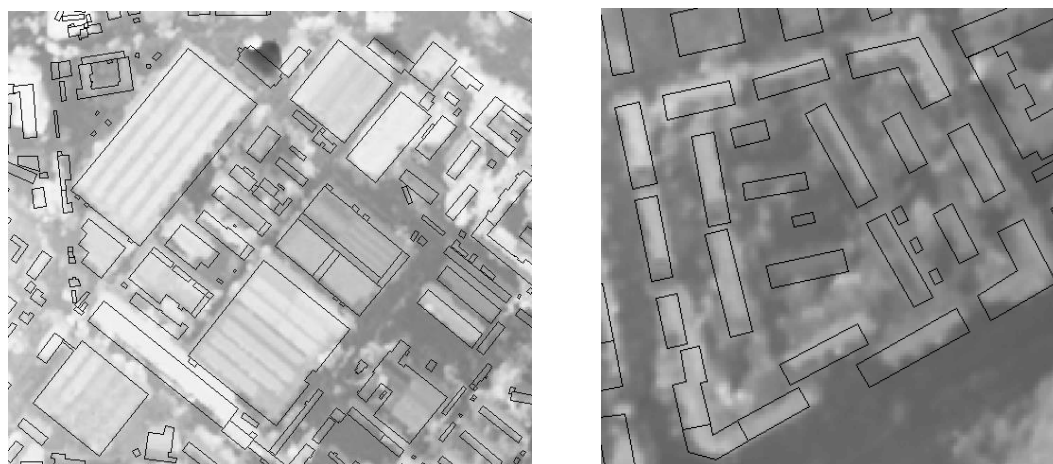

Fig. 4 DSM with Overlaid Vector Models of Buildings

As an additional step in the accuracy assessment, elevation differences were analysed and a scatter plot was constructed. The distribution of differences between the referenced vector topographic layout-derived elevations and the DSM-derived elevations for the ICPs is shown in Fig. 5. A normal distribution can be observed. 71% of all elevation differences are in a range from -2 m to 2 m. A scatter plot of the DSM-derived elevations and reference-derived elevations is shown in Fig. 6. The line of best fit (least-square adjustment algorithm) is marked in red. A strong, positive correlation can be observed.
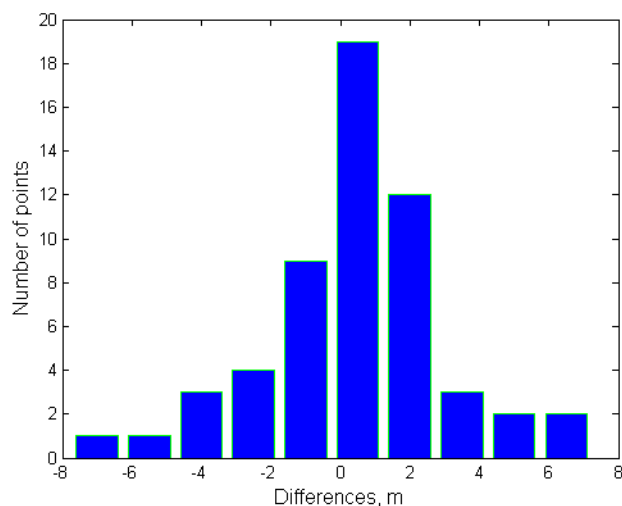
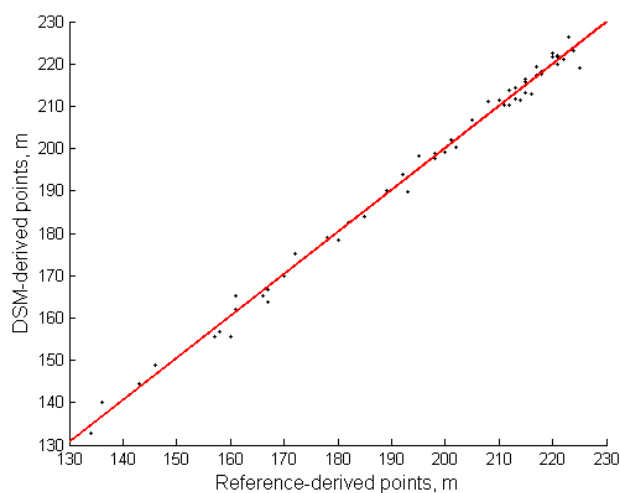**Fig. 5 Distribution of differences between reference-derived elevations and DSM-derived elevations for ICPs**

Fig. 6 Scatter Plot of DSM-derived Elevations and Reference-derived Elevations

5 RESULTS OF ORTHORECTIFIED IMAGES ACCURACY ASSESSMENT

The accuracy assessment of generated orthorectified images was carried out using 16 control points from the paper topographic layout, 1:500 scale. The results are shown in Tabs 3 and 4.

Tab. 3 Results of orthorectified image accuracy assessment generated using extracted DTM

Parameter	Value, m
Systematic error s_x	0,494
Systematic error s_y	-0,953
RMSE$_x$	0,692
RMSE$_y$	0,843
Total RMSE	1,091
CE90	1,647
CE95	1,879
Mean radial error MRE	0,925
Maximum radial error R_{max}	2,510

Tab. 4 Results of orthorectified images accuracy assessment generated using SRTM

Sensor model / Parameter	RPC	RPC0				
	No GCP	1 GCP	2 GCP	3 GCP	4 GCP	5 GCP
Systematic error s_x	0,8811	1,0777	1,0277	0,474	0,412	0,474
Systematic error s_y	-0,752	-0,805	-4,610	0,595	0,408	0,470
$RMSE_x$	1,325	0,875	0,908	0,948	0,902	0,759
$RMSE_y$	0,855	0,814	1,174	1,132	0,976	0,889
Total RMSE	1,577	1,195	1,484	1,477	1,329	1,169
CE90	2,339	1,812	2,234	2,232	2,015	1,769
CE95	2,668	2,068	2,548	2,546	2,299	2,017
Mean radial error MRE	1,397	0,972	1,247	1,315	1,163	1,060
Maximum radial error R_{max}	2,871	3,190	3,563	3,118	2,953	2,144

The results in Tab. 3 show that the geometric accuracy of the orthorectified image generated using the extracted DTM is equal to 1-1.2 m or 2-2.5 pixels. This orthorectified image satisfies the accuracy requirements for topographic layouts with a scale of 1:5,000, according to the standard [18]. An error ellipse with axes 2RMSEx and 2RMSEy is shown in Fig. 7.

If the SRTM is used for orthorectification, then the geometric accuracy of the orthorectified image depends on the chosen sensor model. If only RPCs are used, the total RMSE is equal to 1.58 m or 3 pixels. This value satisfies the accuracy requirements for topographic maps with a 1:10,000 scale. If the RPC0 model with only one GCP is used, the RMSE decreases to 1.19 m. This value satisfies the requirements for topographic layouts with a 1:5,000 scale. Increasing the number of GCPs rather leads to a reduction of systematic errors, but doesn't lead to a significant reduction of RMSEs. An error ellipse with axes 2RMSEx and 2RMSEy is shown in Fig. 7.
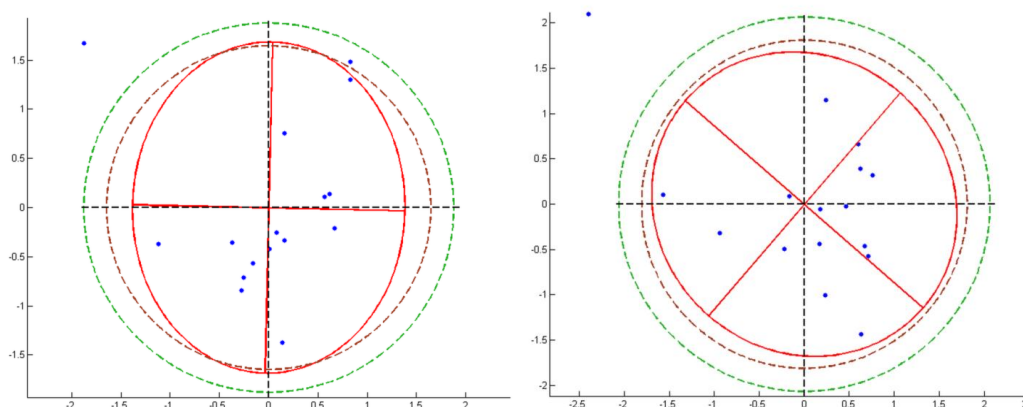

Fig. 7 Distribution of errors in ICPs. Red Colour – error ellipse, Brown – CE90, Green – CE95 (left image– using extracted DTM, right image –using SRTM and 1 GCP)

Vector biases on ICPs with respect to reference are shown in Fig. 8. The biases are random and no systematic errors can be observed.
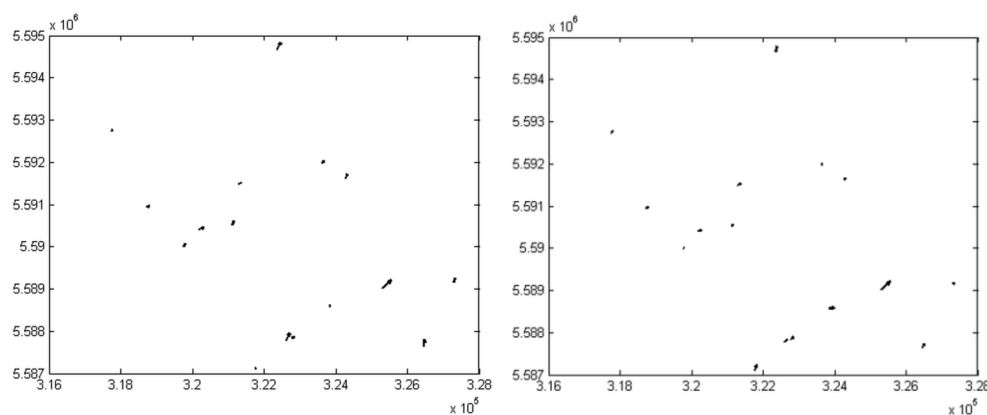

Fig 8. Vector biases in ICP (left image– using extracted DTM, right image –using SRTM and 1 GCP)

This means that the orthorectified imagery generated using the SRTM has approximately equal geometric accuracy as the orthorectified imagery generated using the extracted DTM from the stereo pair. This conclusion is particularly significant in economic terms as a possibility to cut costs while creating orthorectified images.

6 CONCLUSIONS

The vertical accuracy of the DSM extracted from Pléiades 1A stereo pair, and the geometric accuracy of orthorectified imagery generated using the extracted DSM and using the SRTM were analysed in this paper.

In order to assess the extracted DSM, independent check points from the vector topographic layout, 1:2,000 scale, with a vertical interval of 1 m were used. OrthoEngine from PCI Geomatica 2013 was used as the photogrammetric software application both for the stereo pair orientation and the DSM extraction. Tie points were extracted automatically using correlation algorithms for searching identical points in overlapping images. Five GCP and a bias compensation model (RPC0) were used for RPC refinement. A strong, positive correlation between the reference-derived elevations and the DSM-derived elevations can be observed.

In order to assess the geometric accuracy of generated orthorectified images, independent checkpoints from the paper topographic layout, 1:500 scale, were used. It was found that the geometric accuracy of the orthorectified image generated using the extracted DSM and the RPC0 sensor model is 1-1.2 m (or 2-2.5 pixels). This accuracy satisfies the standard requirements for topographic layouts of the 1:5000 scale. Approximately equal geometric accuracy can be achieved using the SRTM and the same RPC0 sensor model for orthorectification.

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