HORIZONTAL ACCURACY ASSESSMENT OF PLANETSCOPE, RAPIDEYE AND WORLDVIEW-2 SATELLITE IMAGERY

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ABSTRACT

Satellite imagery with different spatial resolutions and global daily revisit time provide much information of earth surfaces on a large scale in a short time. Thereby it is necessary to determine the horizontal accuracy of the satellite imagery to enable the possibility of their future everyday use in different application fields like environmental assessment, urban monitoring, forestry management, etc. In this research multispectral (MS) imagery from PlanetScope (PS), RapidEye (RE) and WorldView-2 (WV2) satellites was used for horizontal accuracy assessment. The imagery was obtained at different processing levels (basic – non-orthorectified, ortho – orthorectified). The study area is in Zagreb, the capital city of Croatia. Accuracy assessment was calculated on the 29 randomly distributed control points measured with Topcon HiPer SR receiver connected to Croatian Positioning System, which horizontal accuracy is around 2 cm. PS source imagery (PS_{basic}) with a spatial resolution of 3 m, orthorectified PS imagery (PS_{ortho}) with a spatial resolution of 3.7 m and RE ortho tile (RE_{ortho}) with a spatial resolution of 5 m were obtained through Planet Research and Education program. WV2 OrthoReady Standard ($WV2_{ORS2A}$) with a spatial resolution of 2 m was obtained within Geospatial monitoring of green infrastructure by means of terrestrial, airborne and satellite imagery (GEMINI) project. $WV2_{ORS2A}$ imagery was orthorectified ($WV2_{ortho}$) with Orpheo ToolBox based on the global Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM). Highest accuracy has achieved a $WV2_{ortho}$ image with RMSE of 3.16 m, while lowest accuracy has $WV2_{ORS2A}$ with RMSE of 9.52 m. If we compare source imagery, PS_{basic} with a spatial resolution of 3.7 m has better accuracy then $WV2_{ORS2A}$ with a spatial resolution of 2 m. When comparing downloaded orthorectified imagery from Planet website, PS_{ortho} has better accuracy than RE_{ortho} (RMSE of 4.80 m against RMSE value around 5.40 m). It must be emphasised that with an orthorectification accuracy improves significantly. PS_{ortho} has almost 1.5 higher accuracy than PS_{basic}, while $WV2_{ortho}$ image orthorectified with SRTM DEM has 3 times higher accuracy than $WV2_{ORS2A}$. A further investigation for orthorectification with another freely available DEMs and afterwards geometric correction of satellite imagery would be interesting for using satellite imagery in precise mapping applications.

Keywords: remote sensing, satellite imagery, accuracy assessment, orthorectification.

INTRODUCTION

Satellite imagery with different spatial resolutions and global daily revisit time has become a common part of our information society. Planet, an aerospace company, builds and operates the largest constellation of small imaging satellites. Planet operates with more than 175 PlanetScope, 13 SkySats and 5 RapidEye satellites. PlanetScope (PS) satellite, also called the Dove, collects multispectral (MS) imagery in 4 bands with a spatial resolution of 3 m and a collection capacity of 300 million square km per day. Some applications of the PS imagery are to quantify the extents of land covers and detect their changes [1], open water imaging [2], in agriculture, defence and intelligence, energy and infrastructure. RapidEye (RE) satellite collects MS imagery in 5 bands with a spatial resolution of 5 m and a collection capacity of 6 million square km per day. Useful research with the RE imagery can be conducted for tree species classification [3], enhanced species mapping [4], deriving coastal bathymetry [5]. In 2009, DigitalGlobe company launched WorldView-2 (WV2) satellite. WV2 collects MS imagery in 8 bands with a spatial resolution of 2 m and a collection capacity up to 1 million square km per day. WV2 MS imagery is used in different application fields, such as vegetation and agricultural purposes [6], estimation of sea depths due to the newly added Coastal band [7], green space planning, object mapping, land cover changes etc. Land cover classification accuracy, especially in urban areas can be improved based on the image fusion process [8].

Although satellites have large collection capabilities to produce imagery on a large scale in a short time, it is very important to determine their horizontal accuracy. According to vendor specification [9], RE and PS horizontal accuracy are less than 10 m Root Mean Square Error (RMSE). According to Anderson and Marchisio [10], geolocation accuracy for WV2 imagery is 5 m Circular Error, 90% confidence (CE90). To our knowledge, there have not been much research for assessing the horizontal accuracy of PS imagery, Rios-Olmo and Miller [2] determined relative accuracy over littoral, coastal and open water regions. Nowak Da Costa [11] evaluated the geometric characteristics of the RE image products. Aguilar et al. [12] observed geometric and radiometric characteristics of WV2 MS imagery. Gašparović et al. [13] have tested the spatial accuracy of WV2 imagery, as well as, aerial imagery and Google Earth imagery.

Main goal of this research is to assess the horizontal accuracy of the PS, RE and WV2 MS imagery over the same study area. Previously mentioned satellite imagery has a different spatial resolution. One of the goals of this research is to compare accuracy across a different spatial resolution. As well, increase in the accuracy of the satellite imagery after orthorectification is examined. Previously mentioned imagery is used for monitoring of the urban green infrastructure within Geospatial monitoring of green infrastructure by means of terrestrial, airborne and satellite imagery (GEMINI) project. Thereby it is necessary to determine the horizontal accuracy of the satellite imagery to enable the possibility of their future common use in different application fields.

STUDY AREA AND DATA

The study area is in Zagreb, the capital city of Croatia. Zagreb lies at an elevation of 122 m above sea level with an area of 641 square km. For this research central urban and eastern lowland parts of the city were taken into consideration with an area extent of 90 square km (8.1 km x 11.1 km). The research area is surrounded by a Medvednica mountain on the north and river Sava on the south (Figure 1).

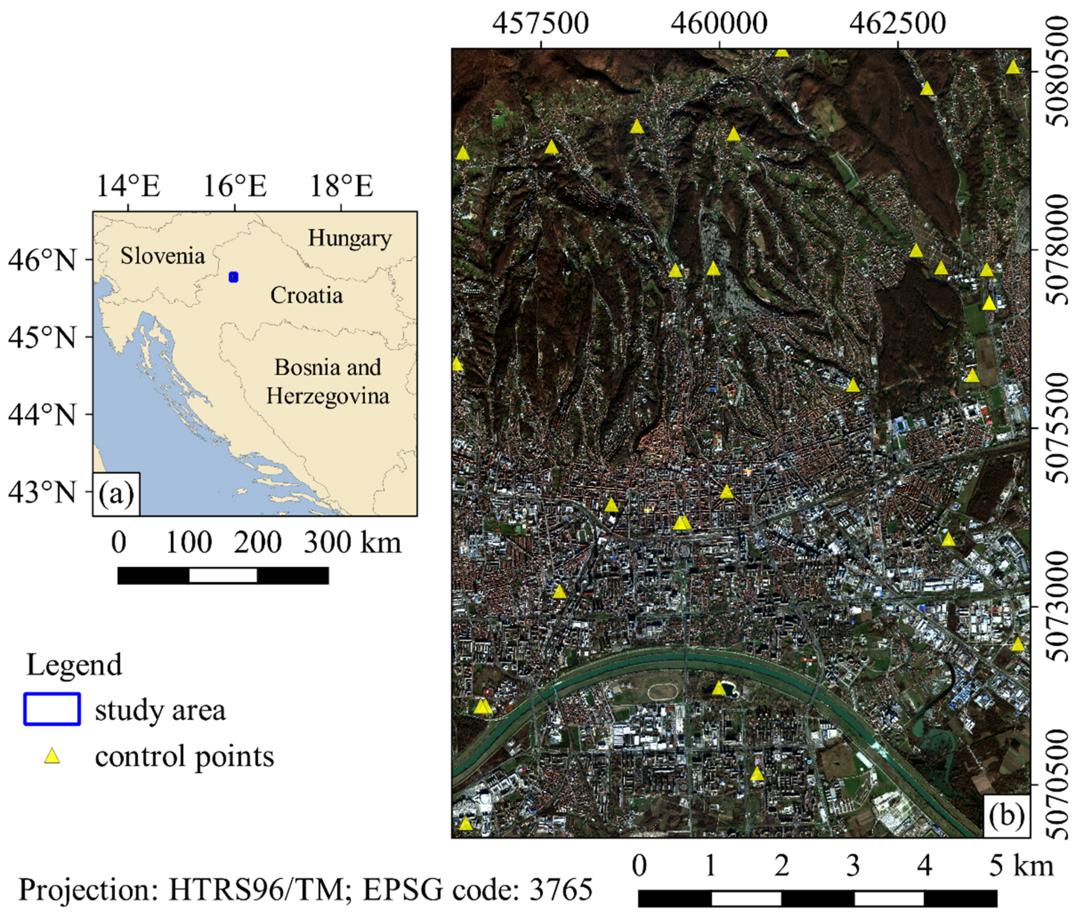

Figure 1. (a) Study area location; (b) distribution of the 29 control points overlaid on the WorldView-2 'true colour' composite (5–3–2), sensing date: 30/11/2016.

For this research, PlanetScope (PS), RapidEye (RE) and WorldView-2 (WV2) satellite imagery were acquired (Table 1). PS 4-band MS analytic data products – Basic Scene (Level 1B) and Ortho Scene (Level 3B) with a spatial resolution of 3.7 m and 3 m, respectively, were used for this research. For PS Basic imagery radiometric and sensor corrections are applied to the data, while PS Ortho Scene is orthorectified and projected to a cartographic projection. RE 5-band MS analytic data product – Ortho Tile (Level 3A) with a spatial resolution of 5 m was used in this research. RE Ortho Tile has radiometric, and sensor corrections applied to the data. Imagery is orthorectified using the Rational Polynomial Coefficients and an elevation model. WV2 OrthoReady Standard (ORS2A) 8-band MS image with a spatial resolution of 2 m was used for this research. ORS2A imagery has no topographic corrections, and it is mapped to the average base elevation of the terrain.

Table 1. Characteristics of MS images acquired at the study area.

Sensor	PlanetScope		RapidEye	WorldView-2
Product type	Basic	Ortho	Ortho Tile	ORS2A
Product level	1B	3B	3A	2A
Product ID	20161207_090319_0e3a 20161207_090320_0e3a		20170216_101808_3360217 20170216_101809_3360218	17EUSI-1583-02_I234123_FL01-P426187
Acquisition date	07/12/2016		16/02/2017	30/11/2016
Acquisition time	09:03:19	10:10:14	10:18:09	10:05:45
Cloud cover	0%		0%	0%
Spatial resolution	3.7 m	3 m	5 m	2 m
Spectral bands	4		5	8

For accuracy assessment of PS, RE and WV2 imagery 29 randomly distributed Control Points (CPs) were recorded using Topcon HiPer SR receiver connected to the Croatian Positioning System (CROPOS). CPs, located on well-defined features and randomly distributed over the study area was chosen for acquired satellite imagery (Figure 2).

(a) (b) (c) (d) (e)

Figure 2. Control point 175 (red colour) and 177 (black coluor) locations: (a) on the field; (b) on the PS basic; (c) on the PS ortho; (d) on the RE ortho; (e) on the WV2.

Each point was measured in 3 sessions of 11 seconds, with reference to the Croatian Terrestrial Reference System 1996 (HTRS96) and Transverse Mercator projection (HTRS96/TM). Digital elevation model (DEM) used for orthorectification of the WV2 imagery is the Shuttle Radar Topography Mission (SRTM) with a spatial resolution of one arc-second (~30 m).

METHODS

Satellite imagery used for this research were PS basic (PS_{basic}), PS ortho (PS_{ortho}) imagery, RE ortho tile (RE_{ortho}) and WV2 ORS2A ($WV2_{ORS2A}$). PS_{basic} has not been processed to remove distortions caused by terrain and is not mapped to a cartographic projection. PS_{ortho} and RE_{ortho} are orthorectified by imagery vendors using Ground Control Points (GCPs) and SRTM DEM (30 to 90 m posting), with positional accuracy less than 10 m RMSE. Orthorectification transforms a central perspective image to an orthogonal view of the ground with uniform scale, which removes the effects of sensor tilt and terrain relief [14]. Horizontal accuracy is significantly improved with orthorectification, which was one of the main goals of this research. Since the $WV2_{ORS2A}$ imagery has no topographic relief (DEM) applied, making it suitable for orthorectification. A process of orthorectification was conducted with the use of open-source software Orfeo ToolBox (OTB) version 6.0.0. OTB algorithm for orthorectification was accessed from Monteverdi. Ancillary data used in this process was SRTM DEM and Rational Polynomial Coefficients (RPCs) which are computed by the imaging companies. For visualisation of used satellite imagery, Quantum GIS (QGIS) version 2.18.11 was used. In this research, horizontal accuracy of high spatial resolution, MS imagery was compared. Statistics were computed on 29 CPs using R programming language, version 3.4.1, through RStudio version 1.0.153. To compare and assess horizontal accuracy, mean error (ME), standard deviation (SD) and root mean square error (RMSE) were computed:

$$\Delta_i = \sqrt{\left(E_{GNSS,i} - E_{image,i}\right)^2 + \left(N_{GNSS,i} - N_{image,i}\right)^2} \tag{1}$$

$$ME = \frac{\sum_{i=1}^{n} \Delta_i}{n} \tag{2}$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n} (\Delta_i - ME)^2}{n-1}} \tag{3}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (\Delta_i)^2}{n}} \tag{4}$$

where Δ is the difference between reference coordinates which are measured with GNSS on the field and coordinates derived from the satellite imagery and n is a total number of points.

To eliminate possible outliers from our measurements X, after computing a results three-sigma rule according to Eq. (5) was applied to our dataset [15]:

$$(ME - 3SD) \leq X \leq (ME + 3SD) \tag{5}$$

RESULTS

In this section results of horizontal accuracy for satellite imagery will be presented. The analysis was made on PS_{basic} and PS_{ortho}, RE_{ortho}, $WV2_{ORS2A}$ and WV2 orthorectified imagery ($WV2_{ortho}$) with SRTM DEM. Accuracy assessment was computed at 29 control points measured on a field. Statistics for horizontal accuracy was computed according to Eq. (2), (3), (4) and presented in Table 2 along with minimal (Min) and maximal (Max) values. No outliers were detected after computing a result according to Eq. (5).

Table 2. Horizontal accuracy assessment on PS, RE and WV2 imagery.

Source	PS_{basic}	PS_{ortho}	RE_{ortho}	$WV2_{ORS2A}$	$WV2_{ortho}$
ME (m)	3.80	2.63	3.04	4.46	2.43
SD (m)	5.25	4.09	4.57	8.56	2.06
RMSE (m)	6.41	4.80	5.42	9.52	3.16
Min (m)	-10.39	-6.20	-8.84	-15.98	-2.68
Max (m)	11.85	11.56	14.33	13.00	5.92

As shown in Table 2, the highest accuracy has $WV2_{ortho}$ image, RMSE = 3.16 m and SD = 2.06 m, while lowest accuracy has $WV2_{ORS2A}$, RMSE = 9.52 m and SD = 8.56 m. If we compare basic imagery, PS_{basic} with a spatial resolution of 3.7 m has better accuracy then $WV2_{ORS2A}$ with a spatial resolution of 2 m. Although orthorectification and geometric correction of the previously mentioned basic imagery have not been done, PS_{basic} has additionally been translated into space. When comparing downloaded orthorectified imagery from PS and RE, PS_{ortho} has better accuracy than RE_{ortho} (RMSE = 4.80 m against RMSE = 5.42 m) which was expected because PS sensor has a better spatial resolution. To compare obtained results, graphical visualisation of horizontal RMSE, SD and ME are shown in Figure 3.

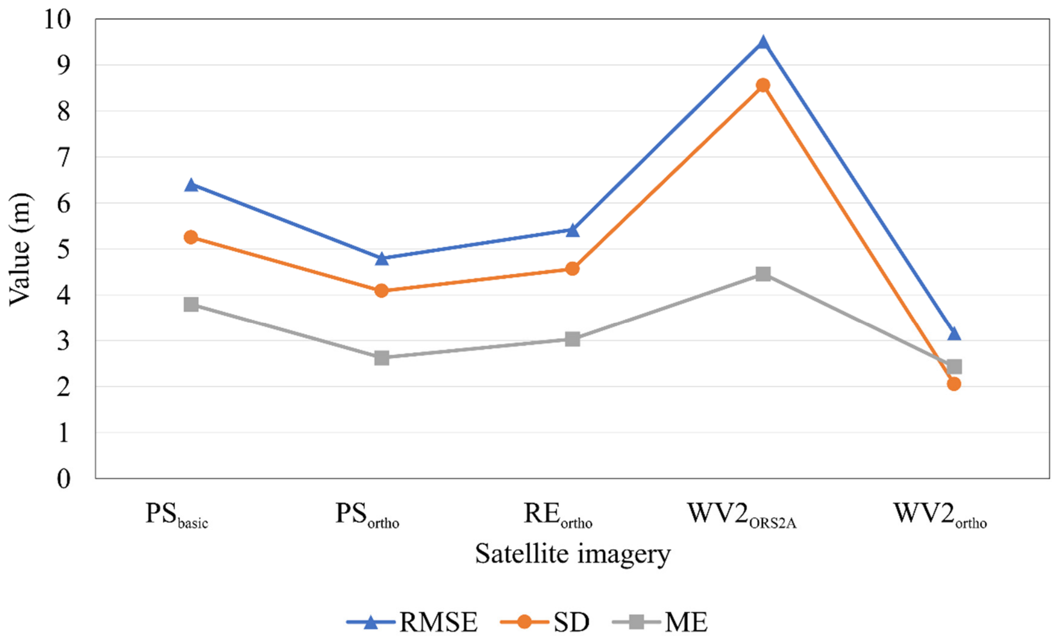

Figure 3. RMSE, SD and ME for PS, RE and WV2 satellite imagery.

Figure 3 shows an increase in accuracy when orthorectification is applied to the imagery. For $WV2_{ortho}$ image ME is higher than SD which leads to the conclusion that higher accuracy can be achieved with additional transformations. The accuracy of the $WV2_{ortho}$ image has increased 3 times after orthorectification $WV2_{ORS2A}$ image, while the accuracy of the PS_{ortho} has increased 1.3 times in comparison to PS_{basic}. For RE, accuracy cannot be compared because only ortho tile product is available while basic imagery is not. If we compare SD values, the precision of the $WV2_{ortho}$ image has increased 4 times in comparison to the $WV2_{ORS2A}$ image and is 2 times higher than PS_{ortho} and RE_{ortho} imagery.

PS_{ortho} has 10% higher accuracy than RE_{ortho} regardless of 67% better spatial resolution (3 m against 5 m). $WV2_{ortho}$ image with a spatial resolution of 2 m has 1.5 times better resolution than PS_{ortho} and 1.5 times higher accuracy, and 2.5 times higher spatial resolution than RE_{ortho} and 1.7 times higher accuracy.

CONCLUSION

In this research accuracy assessment of satellite imagery was made. Available images were PS_{basic} and PS_{ortho} analytic product, RE_{ortho} analytic product and $WV2_{ORS2A}$ imagery. $WV2_{ORS2A}$ has been orthorectified with freely available SRTM DEM. The process of orthorectification and further analysis were made in free and open source programs.

As shown in the previous section, as expected highest accuracy has $WV2_{ortho}$ imagery, while lowest accuracy has a $WV2_{ORS2A}$ image. PS_{basic} imagery has higher accuracy than $WV2_{ORS2A}$ which indicates that it has been additionally corrected by the vendor (spatial resolution of PS_{basic} 3.7 m against 2 m of $WV2_{ORS2A}$). If we compare orthorectified images that were downloaded from Planet website, PS_{ortho} has better accuracy and precision than the RE_{ortho} image. $WV2_{ortho}$ image has a higher ME than SD value which leads us to a conclusion that additional transformations can be made on $WV2_{ortho}$ images. For future investigations, geometric corrections on orthorectified WV2 images can be obtained. It must be emphasised that with an orthorectification accuracy improves significantly. $WV2_{ortho}$ image with SRTM DEM has 3 times higher accuracy and 4 times higher precision than $WV2_{ORS2A}$. PS_{ortho} image has 1.3 times higher accuracy than the PS_{basic} image. RE basic imagery and RE_{ortho} image cannot be compared while only RE_{ortho} image is available for download.

In this research comparison of satellite imagery that is gained from different sensors and has a different spatial resolution was made. Free and open source programs were used (OTB, QGIS, R) along with imagery available for scientific research. A further investigation for orthorectification with another freely available DEMs and afterwards geometric correction of satellite imagery would be interesting for using satellite imagery in precise mapping applications.

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