Accuracy analysis of orthomosaic and DSM produced from sensor aboard UAV

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Abstract: This paper deals with geometric quality analysis of an interest area mapping that followed all the steps of a photogrammetric aerial survey. We performed flight planning, GNSS survey of ground control points and ground check points, digital aerial imaging using a small format digital camera onboard a small unmanned aerial system, GNSS post processing and photogrammetric processing. Pix4D photogrammetry software was used to process images and coordinates in order to generate a digital orthophoto mosaic and a Digital Surface Model – DSM, both with and without Ground Control Points – GCP. Our main objective was to evaluate these generated products regarding positional accuracy compliance to Brazilian Cartographic Accuracy Standard for Digital Products – PEC-PCD using a mathematical model of statistical analysis and error vector plot. We also analyzed the information presented on quality report from Pix4D regarding consistency. All planned data were collected and the results were fully achieved. The mapped area using GCP reached a quality level class A at 1:1000 scale in orthomosaic and class A at 1:500 scale in DSM. Orthomosaic without GCP reached class A only at 1:10000 scale and DSM without GCP was not possible to classify in any class or scale due to large vertical errors.

Keywords: Digital Aerial Photogrammetry, Mapping, Digital Surface Model – DSM, Brazilian Cartographic Accuracy Standards for Digital Products – PEC-PCD, Ground Sample Distance – GSD.

1. Introduction

Nowadays, with advent of new technologies such as Unmanned Aerial Vehicles – UAV, drones and compact digital cameras, aerial survey and photogrammetry activities have been undergoing major changes. Some paradigms are being broken, making such activities more accessible in several areas of technical community, Abramson (2012).

Many sectors of scientific, military and productive society in Brazil are turning their eyes to this new reality and creating different solutions for mapping, monitoring, tracking, inspection and detection of specific targets. The main difficulties at this point are the legal restrictions, still under discussion in the country, and the quality of this information regarding positional accuracy for planimetry and altimetry on aerial mapped products.

Photogrammetry from UAV comprises the use of an aerial photogrammetric survey platform that can be remotely operated, semi or fully autonomously. In general platform carries a common or infrared digital camera system to capture images, a GNSS receiver to provide position for each frame, a Inertial Measurement Unit – IMU composed by gyroscopes, accelerometers, barometers and compass, which allows determination of the exterior orientation for each image taken during the flight, a small CPU that controls all systems and a radio link that enables data download and human control by a remote system.

Processing software developed for UAV image have a much larger automation compared with the classical photogrammetry software, because they use computer vision algorithms that process a lot of images. They are optimized and of simple operation for the generation of products with less control on the processing steps and on accuracy of the geometric orientation parameters. Require as minimum input only the images and the coordinates of each frame. Camera calibration parameters and external orientation angles (ω, ϕ, κ) are optional because the software can determine them implicitly at aerial triangulation and block adjustment, although with low accuracy. So when seeking quality, this data are recommended.

According Kung *et al* (2011) and Ferreira *et al* (2013), automatic photogrammetric processing can be completed only with positions from onboard GNSS, but for better accuracy is convenient to use Ground Control Points – GCP and check points for quality control. As the images obtained from UAVs have few centimeters GSD, to maintain positional accuracy in that order, GCP survey must be performed with appropriate procedures. Block formation and georeferencing may be difficult especially when image positions and slopes are adverse or when mapping areas with uniform texture as water surface and vegetation.

In this work, all the steps for a photogrammetric aerial survey were followed: flight planning; GCP and check points survey with GNSS receiver; digital aerial imaging using a small format digital camera onboard a UAV; GNSS processing data and photogrammetric processing to generate a digital orthophoto mosaic and a DSM, both with and without GCP. The main objective was to analyze the geometric quality of generated products. Positional accuracy compliance to standard PEC-PCD was evaluated using a mathematical model for statistical analysis. Results presented in Pix4D Quality Report were also analyzed.

2. Methodology

The experiments were conducted in an area inside the campus of University of Paraiba Valley – UNIVAP, located in São José dos Campos, SP, Brazil. The area is close to the aeromodelling center of the city where the university is authorized to perform test flights.

2.1 Equipment

The UAV used was a Phantom4, quadcopter type, designed and assembled by DJI company (2016), able to work autonomously, offering five cameras, including the FC330 with 12MP RGB used in this aerial survey, as illustrated on Figure 1.


(a)

(b)

Figure 1. Phantom4 UAV (a) and FC330 camera (b).

GNSS receivers used for GCP and check points survey were the GTR-G2 model from TechGEO manufacturer with 72 channels and frequencies capability L1 and L2 both GPS and GLONASS constellations, with pinwheel technology antenna to minimize multipath effects.

2.2 Softwares

Mission Planner from ArduPilot (2016) was used for flight path previous definition. Photogrammetric processing of images from UAV was done using Pix4D Mapper Pro. That calculates position and original image orientation by Automatic Aerial Triangulation – AAT and Bundle Block Adjustment – BBA, DSM is generated based on 3D cloud point obtained from AAT and BBA, according Wolf (1985) and Mikhail and Bethel (2001). The ortho-rectification and mosaicking is performed from the projection and combination of original images with DSM, as showed in Pix4D manual (2013).

GNSS differential processing of CGP and check points was conducted with GTR Processor v2.92. Statistical analysis and graphing were done in MATLAB v7.11 R2010b.

2.3 Data Acquisition and Processing

Flight was planned to cover a 15 hectare area, with 50 m of average height to reach 2cm GSD, 60% lateral and 80% longitudinal overlap. The interest area contained uniform regions like grass, flat roofs and tall objects related to flight height, such as trees and buildings top.

Data and images were processed in automatic mode on Pix4D, firstly processing with 7 GCP and secondly without. Input data provided to the software were only images and coordinates from onboard GNSS. Both processing generated orthomosaic and DSM for planimetry and altimetry positional accuracy analysis. So, 40 GNSS check points were collected in the field, in addition to the GCP, according study conduct by Merchant (1982) which requires at least 20 points chosen homogeneously and comprehensively in the area.

Still according Merchant (1982), accuracy required for check points must be 1/3 of the desired accuracy for orthomosaic. So, a GNSS base point survey was planned within the area by 4 hours static positioning and differential post-processing performed using SJSP station from Brazilian Network of Continuous GNSS Monitoring - RBMC, located on INPE, about 10 km baseline. Thus, the GCP and check points could be measured by fast-static positioning for post-processing related to the base point, reaching under decimeter accuracy.

2.4 Positional Accuracy Evaluation

Quality evaluation of processed data were performed according standard PEC-PCD, Table 1, established by ET-ADGV Technical Specification from Brazilian Army Geographic Service Directory - DSG (2016), an update of PEC from Decret n^{o} 89817, Brasil (1984).

Table 1. Brazilian cartographic accuracy standard for digital products.

CLASS	Planimetry		Altimetry[1]	
	EP [mm]	PEC [mm]	EP [eq]	PEC [eq]
A	0,17	0,28	1/6	0.27
B	0,30	0,50	1/3	1/2
C	0,50	0,80	2/5	3/5
D	0,60	1,00	1/2	3/4

[1]values for quota points or DEM/DTM, eq = level curves equidistance.

Values in Table 1 should be multiplied by scale denominator (planimetry) or equidistance (altimetry) to obtain values on the corresponding scale. EP is the standard error or standard deviation and PEC the value for the 90% probability in the north, east or vertical components.

Methodology used to evaluate orthomosaic and DSM according PEC-PCD is shown on Figure 2, a combination of already established in Brazilian literature by Brito (1987), Tommaselli *et al* (1988) and Galo and Camargo (1994), in addition to concepts presented by the American Society for Photogrammetry and Remote Sensing - ASPRS (2014).

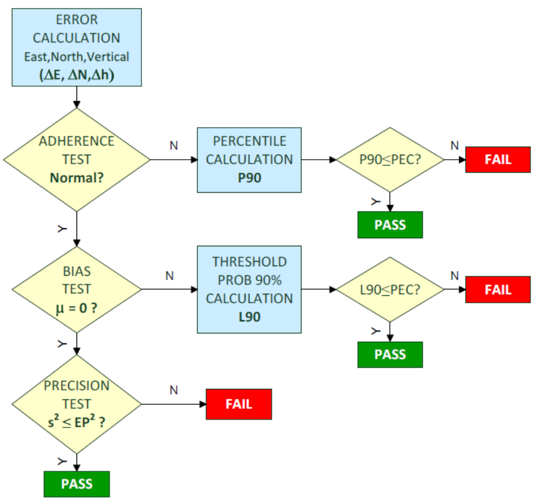

Figure 2. Methodology for orthomosaic and DSM accuracy evaluation.

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3. Results and Discussion

3.1 Ground Control Points and Check Points

GNSS photo-referenced points were measured on the field according above methodology. The geodetic point on RBMC station provided high accuracy to the base point surveyed in the study area, as shown on Table 2. This provided maximum standard deviation of 7mm in planimetry and 30mm in altimetry for GCP and check points, Figure 3.

Table 2. Reference points for GNSS differential post-processing.

	RBMC SJSP Station	σ [m]	UNIVAP Base Point	σ [m]
Latitude	23°12'25.6767"	0.002	23°12'42.1521"	0.004
Longitude	45°51'42.2560"	0.003	45°57'54.3711"	0.004
h [m]	605.089	0.016	565.092	0.017

Reference System: SIRGAS-2000

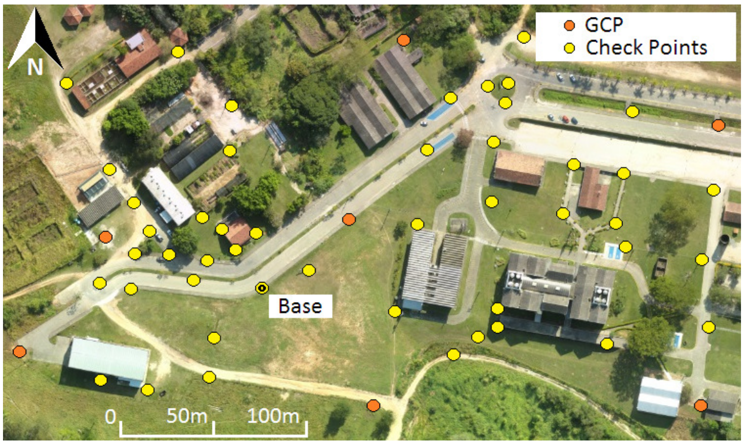
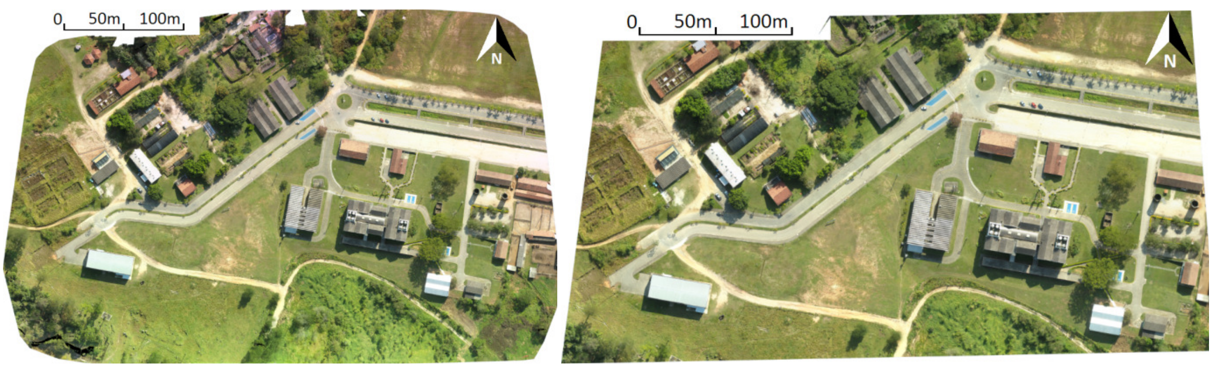


Figure 3. Geographic arrangement of GCP and check points surveyed with GNSS.

3.2 Photogrammetric Digital Data Processing

Photogrammetric products like orthomosaic and DSM were generated automatically in Pix4D both with and without GCP, according to description on 2.3 item. Low features in orthomosaic such as sidewalks were well defined, but high features such as top of trees were not. Buildings were geometrically well defined. Central region, with five or more images overlap, provided better results than edges. Orthomosaic can be considered an ortophoto true, because the oblique views of vertical planes on buildings facades were eliminated.



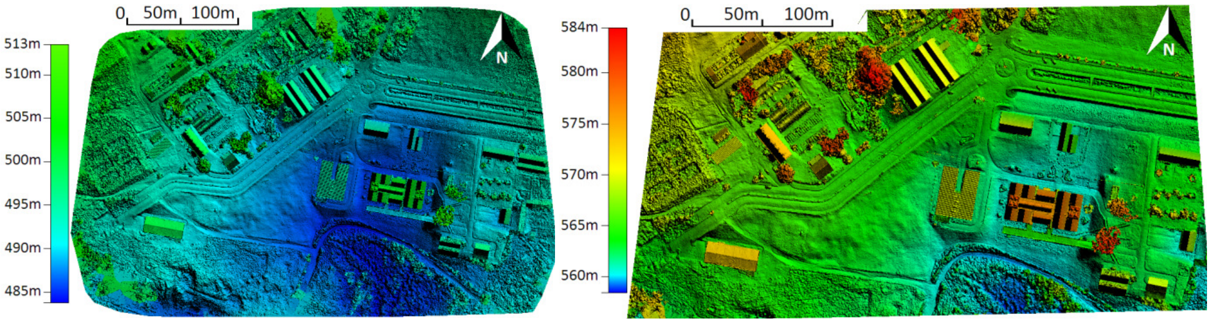
(a) (b)

Figure 4 – Orthomosaic with 2,10cm GSD processed without GCP (a) and with GCP (b).

Visual analysis of some GNSS surveyed points was performed comparing with location where orthomosaic indicated for that coordinate, as shown in Figure 5.

Figure 5. Coordinates shift in orthophotos compared to GNSS survey.

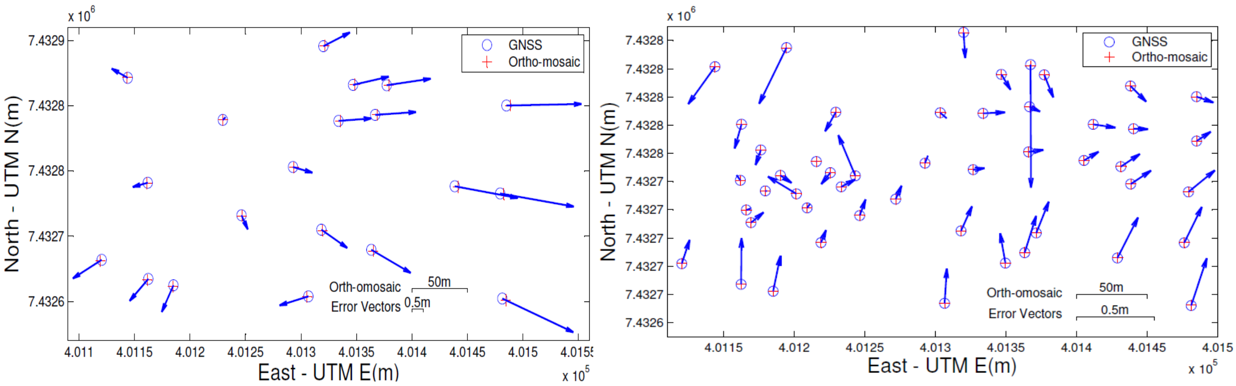
Hypsometric map on Figure 6 shows that DSM is consistent with the ground altimetry and has reliable representation of sudden variations from elements such as buildings and trees.



(a) (b)

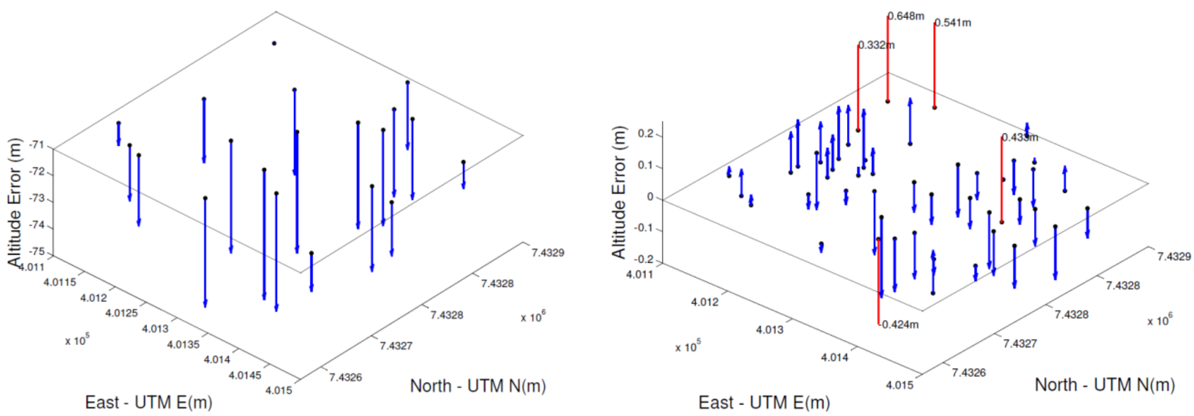
Figure 6. Digital Surface Model processed without GCP (a) and with GCP (b).

Errors were computed for all check points at three components East, North and Vertical. The results are shown in Figures 7 and 8, where error vectors were expanded in relation to graphic scale for better visualization.



(a) (b)

Figure 7. Planimetry error vectors for orthomosaic without GCP (a) and with GCP (b).



(a) (b)

Figure 8. Altimetry error vectors for DSM without GCP (a) and with GCP (b).

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Statistical sample parameters were obtained from calculated errors and used for PEC-PCD compliance verification and comparison to Pix4D Quality Report results, Table 3.

Table 3. Statistical parameters from check points and from Pix4D quality report.

		With GCP			Without GCP		
		Check Points	Pix4D		Check Points	Pix4D	
Mean [m]	$\overline{\Delta E}$	0.045	0.003	☑	0.984	0	☑
	$\overline{\Delta N}$	0.059	-0.003	☑	-0.292	0	☑
	$\overline{\Delta h}$	-0.017	-0.017	☑	-73.875	0	☒
Standard Deviation [m]	S_E	0.077	0.079	☑	1.549	1.810	☑
	S_N	0.161	0.119	☒	0.515	0.633	☑
	S_h	0.190	0.053	☒	1.342	1.367	☑
Root Mean Square [m]	RMS_E	0.087	0.080	☑	1.802	1.810	☑
	RMS_N	0.168	0.119	☒	0.581	0.633	☑
	RMS_D	0.189	0.144	☒	1.893	1.920	☑
	RMS_h	0.186	0.056	☒	73.887	1.367	☒

Mean values from Pix4D were true, according hypothesis test, except for DSM without GCP where high vertical systematic error occurred impacting RMS value. Dispersion values from Pix4D were true for product without GCP, although high, but optimistic with GCP.

According to Monico (2007), many factors affect error in absolute GNSS positioning, that used onboard in UAV. The main factor is ionosphere signal delay. This causes systematic errors and wide dispersion on coordinates, impacting directly and inevitably the positional accuracy of cartographic products without GCP, regardless of processing quality from photogrammetric software.

3.3 PEC-PCD Evaluation

The quality of products (orthomosaic and DSM) generated by Pix4D was evaluated according standard PEC-PCD based on check points, using methodology presented on 2.4 item. Adherence of samples to the normal probability distribution was verified by quantile-quantile graphs as examples shown on Figure 9.

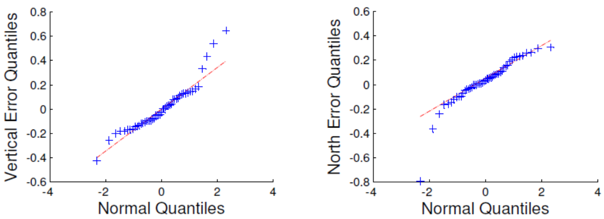

Figure 9. Adherence to the normal probability distribution analysis.

3.3.1 Bias Analysis

Verification of systematic errors on east, north and vertical components was made through hypothesis test, such as example of east component shown in Equation 1. Statistics were calculated from sample mean and standard deviation, based on t-student probability distribution with "n-1" degrees of freedom, according to Equation 2.

$$\begin{aligned} H_0&: \mu_E = 0 \\ H_1&: \mu_E \neq 0 \end{aligned} \qquad (1)$$

$$t_{c_E} = \frac{\overline{\Delta E} - 0}{S_E/\sqrt{n}} \sim t_{n-1} \qquad (2)$$

Critical values $t_{\alpha/2,(n-1)}$ and $t_{1-\alpha/2,(n-1)}$ were obtained, i.e., the theoretical limits of non-rejection region on t-student distribution for a significance level $\alpha = 0.01$, and compared to the calculated statistic t_c. The null hypothesis H_0 was rejected when $t_c > t_{1-\alpha/2,(n-1)}$ or $t_c < t_{\alpha/2,(n-1)}$

and not rejected otherwise. The results in Table 4 show that orthomosaic with GCP have no bias, but orthomosaic without GCP showed high systematic error on vertical component, certainly due low accuracy of absolute positioning from GNSS onboard.

Table 4. Bias analysis results.

	With GCP			Without GCP		
Component	t_c	Mean [m]	Result	t_c	Mean [m]	Result
East	3.180	0.045	☑	2.843	0.984	☑
North	0.986	0.059	☑	2.539	-0.292	☑
Vertical	0.327	-0.017	☑	246.214	-73.875	☒

3.3.2 Precision Analysis

Compliance verification to PEC-PCD was made by precision analysis of each component through hypothesis test unilateral to right, adopting the null hypothesis of variance being statistically equal to or less than the square standard error (EP) for each class and scale established on PEC-PCD, such as example the north component shown in Equation 3. Statistics were calculated based on chi-square probability distribution with "n-1" degrees of freedom, according to Equation 4, where "n" is the number of check points.

$$\begin{aligned} H_0&: s_N^2 = EP^2 \\ H_1&: s_N^2 > EP^2 \end{aligned} \quad (3)$$

$$x_{c_N} = \frac{(n-1)s_N^2}{EP^2} \sim \chi^2_{n-1} \quad (4)$$

Critical value $x_{\alpha,(n-1)}$ was obtained, i.e., the theoretical limit of the non-rejection region on chi-square distribution for a significance level $\alpha = 0.01$ and compared to calculated statistic x_c. The null hypothesis H_0 was rejected when $x_c > x_\alpha$ and not rejected otherwise, Table 5.

Table 5. Compliance verification of products to PEC-PCD.

	With GCP	Without GCP
Planimetry	(90% < 31cm) A 1:1000	(90% < 3,37m) A 1:10000
Altimetry	(90% < 27cm) A 1:500	(90% ~ 76,10m) None

4. Conclusions and Recommendations

All planned data for this study were collected and the objective for evaluating geometric quality of photogrammetric products generated from UAV picture was successfully achieved.

Orthomosaic and DSM with GCP had errors lower than 30cm, fitting to high classes and scales of standard PEC-PCD, while products without GCP had major errors. Thus, for products that require accuracy, GCP survey is mandatory. Still, it is recommended to provide to photogrammetry software, in addition to images and their coordinates, the external orientation angles (ω, ϕ, κ) and precise parameters of camera calibration.

Most of accuracy values provided on Pix4D quality report were true but some showed be optimistic. Pix4D software is user interactive and contains analysis tools, however, more restrict than classic photogrammetry software regarding interactions for adjustments of links and injunctions. The data collection system, Phantom4, showed to be functional but low flight autonomy, so indicated for small and medium-sized projects.

The effectiveness of using UAV images for generation of cartographic products should be evaluated specially in critical areas such as that with large dimensions, or those with large elevation variations, or containing large homogeneous regions, i.e., lacking in detail for automatic images orientation in mosaicking.

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