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Validation of the positional accuracy of products resulting from the digital processing of UAV images[1]

Validação da acurácia posicional dos produtos resultantes do processamento digital de imagens de VANTs

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HIGHLIGHTS:
The choice of UAV image processing software should be based on the cost and the accuracy achieved by the product.
Pre-signaled targets for GCP measurements should be visible in their planning, implementation and size, according to a given GSD.
The distribution and quantity of GCPs are fundamental in the altimetric and planimetric analysis of products obtained.

ABSTRACT: Unmanned aerial vehicles (UAVs), also known as drones, are being increasingly applied in different demands and applications, mainly in mapping. Despite the agility and practicality provided by this technology, the image processing software programs currently available on the market are costly and cannot meet teaching/research demands, especially in Brazilian public universities. In this context, this study aimed to evaluate the positional accuracy of products resulting from the digital processing of UAV images using commercial software (Agisoft Metashape) and open-source software (Opendronemap). The planimetric accuracy of the orthophoto mosaic resulting from the two software was not acceptable according to the tolerances defined in the standardization document for planimetric and altimetric accuracy for digital geospatial data, established by the ASPRS (American Society for Photogrammetry and Remote Sensing). Only the altimetric accuracy corresponding to the DEM produced by Opendronemap was satisfactory.

Key words: remotely piloted aircraft, digital elevation model, orthophoto mosaic

RESUMO: Os veículos aéreos não tripulados (VANTs), também conhecidos como drones, estão sendo cada vez mais utilizados em diversas demandas e aplicações, principalmente em mapeamento. Apesar da agilidade e praticidade fornecidas por essa tecnologia, os softwares de processamento de imagens existentes no mercado, possuem um custo muito elevado de forma a não atender as demandas do ensino/pesquisa principalmente das universidades públicas brasileiras. O objetivo desse estudo é avaliar a acurácia posicional dos produtos resultantes de processamento digital de imagens de VANTs a partir de um software comercial (Agisoft Metashape) e um outro de código aberto (Opendronemap). O resultado da acurácia planimétrica do ortofotomosaico decorrente dos dois programas não foi aceitável segundo as tolerâncias definidas no documento de padronização de acurácia planimétrica e altimétrica para dados digitais geoespaciais, estabelecido pela ASPRS (American Society for Photogrammetry and Remote Sensing). Somente a acurácia altimétrica correspondente ao MDE produzido pelo Opendronemap foi satisfatória.

Palavras-chave: aeronave remotamente pilotável, modelo digital de elevação, ortofotomosaico

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Introduction

Unmanned aerial vehicles (UAVs), also known as drones, are being increasingly employed in various demands and applications (Rodrigues et al., 2018), such as in environmental monitoring (Young et al., 2021) and precision agriculture (Klauser & Pauschinger, 2021; Tsouros et al., 2020), as well as in different types of mapping, i.e., topographical (Quispe Enriquez, 2015) or soil (Wu et al., 2019), geological (Vasuki et al., 2014; Dandar et al., 2018) or geomorphological-themed (Papakonstantinou et al., 2016), among others.

Despite the agility and practicality offered by drone technology, its application is still unfeasible considering the technological reality of educational institutions, especially public universities. The aircraft and drone image processing software programs available on the market today are still very costly and, thus, incapable of meeting teaching/research demands. The Agisoft Metashape for example, is a commercial 3D reconstruction software available in standard and pro versions (Rahaman & Champion, 2019).

Low-cost options, however, are also available, such as free image processing software. Rahaman & Champion (2019) tested the performance of open-source software programs, for example, VisualSfM and Python, to support the Structure-from-Motion system for 3D reconstruction using the Agisoft Metashape program. Jaud et al. (2019) compared the generated orthophoto mosaic and the Digital Elevation Model (DEM) products obtained using Metashape and the French open-source software, MicMac, showed that the quality of the DEM is linked to the perfect flight plan strategy, distribution of control points and the VANT sensor optical camera model.

In this context, the present study aimed to evaluate the positional accuracy of products resulting from UAV image processing using commercial software (Agisoft Metashape) and open-source software (Opendronemap).

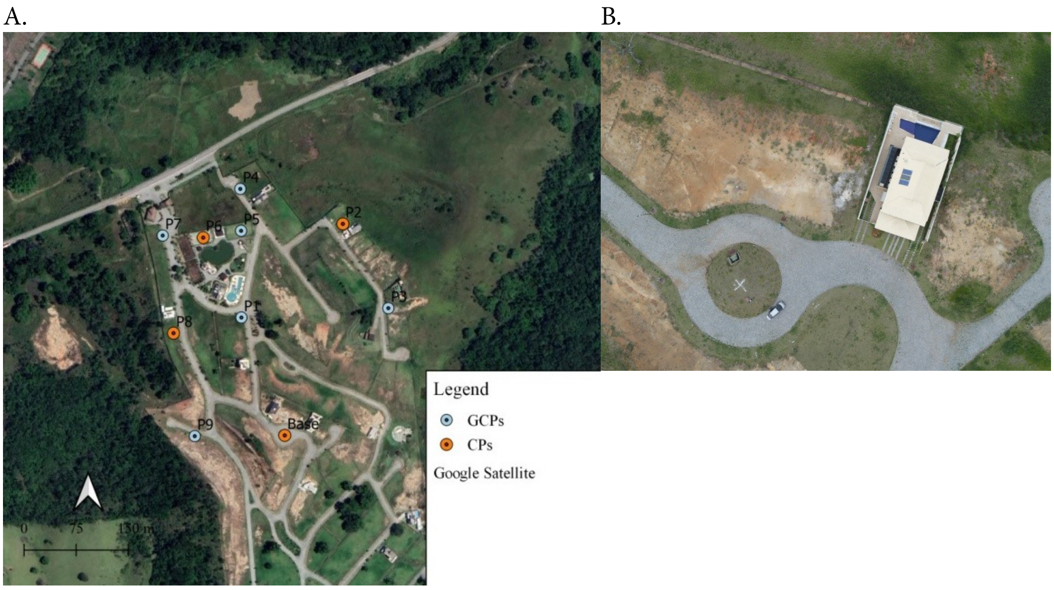
Material and Methods

This study was conducted at the Pedra do Vale Condominium, located in Maricá, state of Rio de Janeiro, southeastern Brazil, with central coordinates of 42° 19’ 10” W and 22° 28’ 17” S (Figure 1A). Its execution considered the following activities: survey of filed control points, automatic flight plan for image acquisition with UAV, digital image processing and planimetric positional accuracy of the products obtained by UAV images.

To perform the tracking of the control points, the relative mode positioning method was used. A reference station (base) was installed and processed by the online service for post-processing of GNSS data, the IBGE-PPP (positioning by Precise Point), which processes GNSS data collected by receivers of one or two frequencies, to allow obtaining coordinates referenced to SIRGAS 2000 (Geocentric Reference System for the Americas) and the ITRF (International Terrestrial Reference Frame) (IBGE, 2021). With the base coordinates calculated, the correction of those collected by the rover was made.

The GNSS receiver used in the base station was Zenite L1/L2 from Tech GEO belonging to the Center for Studies in Coastal Environments of the Fluminense Federal University, considering the tracking time from two to three hours to reach an estimate of centimeters accuracy. Another equipment of the same brand and model occupied the locations of the other control points, measuring in a tracking time from 10 to 15 min to estimate accuracy of 5-10 mm + 1 ppm (IBGE, 2021). In these locations, pre-flagged photogrammetric targets were marked on the ground with lime paint to facilitate the location of targets in the image (Figure 1B). The data from the base and the rovers were processed in the Ezsurv software (Ezsurv, 2021), and MAPGEO software was used to convert geometric to orthometric height.

The distribution of control points in the study area, representing six GCPs (ground control points) and four



GCPs – Ground control points; CPs – Check-points

Figure 1. Distribution of field support points throughout the study area, illustrated by a Google Satellite image (A) and an example of a pre-signaled photogrammetric in one of the UAV images acquired on-site (B)

CPs (checkpoints) alternately, can be seen in Figure 1A. Although this number of support points does not meet the recommendations found in the literature (Tonkin & Midgley, 2016; Martínez-Carricondo et al., 2018; Villanueva & Blanco, 2019), it was decided to use them to assess the impact caused on the results of digital processing of UAVs images.

Flight planning was performed to acquire imagery with the DJI Phantom 4 Pro UAV by the DroneDeploy automatic flight plan application. Although it is a commercial software, it provides a temporary version for students. This application facilitates the control of the UAV to respect the flight ranges and the predefined height. The values of the parameters necessary for the fight operation were entered according to the requirements of the application itself. They may vary according to the purpose of the study (Dronedeploy, 2021): flight height (100 m), image overlap index 75% front and 70% sidelap). Flight speed (approximately 10 m s^{-1}), flight area (about 0.22 km^2), ground sample distance (GSD) equal to 2.5 cm and automatic focal length. EMBRAPA (2018) describe flight parameters indicating the recommended values for three types of DJI UAVs, in the form of tables.

With the aerial images acquired, digital processing was performed using two 3D reconstruction software, Agisoft Metashape and Opendronemap. Based on the SFM (Structure from Motion) technique, a technique used to obtain topographic data from digital images, the existing algorithms in this software produce two sets of data, a sparse and a dense point cloud (Marteau et al., 2016), as the following workflow: inserting GCPs, aligning photos, tagging GCPs in photos, generating point cloud, optimizing photo alignment, generating 3D models, DEM, and orthophoto mosaic. The choice of Agisoft Metashape software was because it is commercial and has high acceptance in the market. Opendronemap for being an open-source software and for presenting common operability that allows conducting an adequate comparison of the functionalities and performance of both.

The last step was to perform the positional accuracy of the products generated by the two-image processing software. The SFM platform automatically calculates the RMSE of the control points (GCPs) provided by the two software for analysis. Then, the coordinates of all points obtained by the 3D modelling captured in the generated image were tabulated to calculate the difference of these coordinates with those of the respective checkpoints (CPs) to obtain root mean square errors (RMSE), provided by Eqs. 1 to 4 (Jiménez-Jiménez et al., 2021):

$$RMSE_x = \sqrt{\frac{\sum_i^n (xc_i - xv_i)^2}{n}} \quad (1)$$

$$RMSE_y = \sqrt{\frac{\sum_i^n (yc_i - yv_i)^2}{n}} \quad (2)$$

$$RMSE_z = \sqrt{\frac{\sum_i^n (zc_i - zv_i)^2}{n}} \quad (3)$$

$$RMSE_r = \sqrt{RMSE_x^2 + RMSE_y^2} \quad (4)$$

where:

$RMSE_x$, $RMSE_y$ and $RMSE_z$ - root mean square error in x, y and z, respectively;

$RMSE_r$ - horizontal root mean square error (xy);

xc_i, yc_i and zc_i - GCP coordinates marked in the image;

xv_i, yv_i and zv_i - CP coordinates; and,

n - number of checkpoints.

The coordinates of the image points used in the equations comprise planimetric and altimetric precision calculations performed by the Geographic Information System (GIS) platform (QGIS 3.16 "Hannover") software using the "coordinate copy" tool. The MDE was converted from Geo Tiff format to ASCII using the "Raster convert (file)" tool to read the Z dimension.

The Cartographic Accuracy Standard (CAS) is usually employed to determine absolute accuracy, regulated by Brazilian cartographic technical standards, Decree No. 89,817, established on 06/20/1984, employed to standardize verified cartographic products (Brasil, 1984; IBGE, 2017). The CAS was not employed since no topographic maps were used but geospatial data. Furthermore, CAS instructions are aimed at scales limited to Brazilian systematic mapping, ranging from 1:1,000,000 to 1:25,000.

The standard established by the Accuracy Standards for Digital Geospatial Data (ASPRS) and the National Standard for Spatial Data Accuracy (NSSDA) were, thus, applied. This document includes precision, with established thresholds for digital planimetric and altimetric (Table 1) data, regardless of map scale or contour line range. The defined values of these thresholds are based on ground sample distance (GSD), resulting in the representation of the image pixel in terrain units, usually in centimeters (ASPRS, 2015).

Table 1. Horizontal precision standards for planimetric digital data and vertical precision standards for digital altimetric data

Horizontal accuracy class	Absolute accuracy			Orthophoto mosaic tolerance (cm)
	RMSE x and RMSE y (cm)	RMSE r (cm)	Horizontal accuracy at a 95% confidence level (cm)	
X * cm	≤ X	≤ 1.414 * X	≤ 2.448 * X	≤ 2 * X
for X = 5 cm	5	7.07	12.24	10
Vertical accuracy class	**Absolute accuracy**			
	RMSE z (DTM)	**DTM at a 95% confidence level**	**DEM at a 95% confidence level**	
X * cm	≤ X	≤ 1.96 * X	≤ 3.00 * X	

RMSE - Root mean square errors; DEM - Digital elevation model; DTM - Digital terrain model

There is also another technical specification standard for the quality control of geospatial data, produced by the Brazilian army (Norma EB-80-N-72.004), which has been used by producers of geospatial information from public and private institutions (Brasil, 2016). However, it was discarded because it also considers the scale and not the GSD to evaluate the altimetric and planimetric quality of vector geospatial products.

Results and Discussion

The drone flight was performed using automatic flight planning at 100 m altitude and 2.5 cm GSD, taking approximately 300 photos of a 0.22 km² area.

The UAV image processing products obtained using the Opendronemap (Figures 2A and B) and Agisoft Metashape (Figures 2C and D) software included the orthophoto mosaic and the Digital Elevation Model (DEM). Both software provided quality reports concerning control point post-processing, reporting RMSE (xy), RMSE (z) and GSD values (Table 2).

Table 2. Quality report concerning the post-processing of the applied control points (GCPs)

Software	RMSE x (cm)	RMSE y (cm)	RMSE z (cm)
Opendronemap	4.70	3.50	9.30
Metashape	1.21	1.01	0.51

RMSE - Root mean square error

The values shown in Table 2 indicate good RMSE results with the GCPs used in the image processing provided by the evaluated software. Villanueva & Blanco (2019) assessed the quality of the DEM to optimize the distribution and quantity of control points used in the digital processing of VANT images, by Agisoft Metashape software. According to the author, the more distributed the GCPs are positioned in an area, the less error there will be, and the more concentrated the GCPs are placed, the greater the RMSE. In its graphic evaluation correlating the number of six GCPs corresponding to the class configuration of the well-distributed control points, the planimetric and altimetric RMSE error values are very close to the values given in Table 2. However, Sanz-Ablanedo et

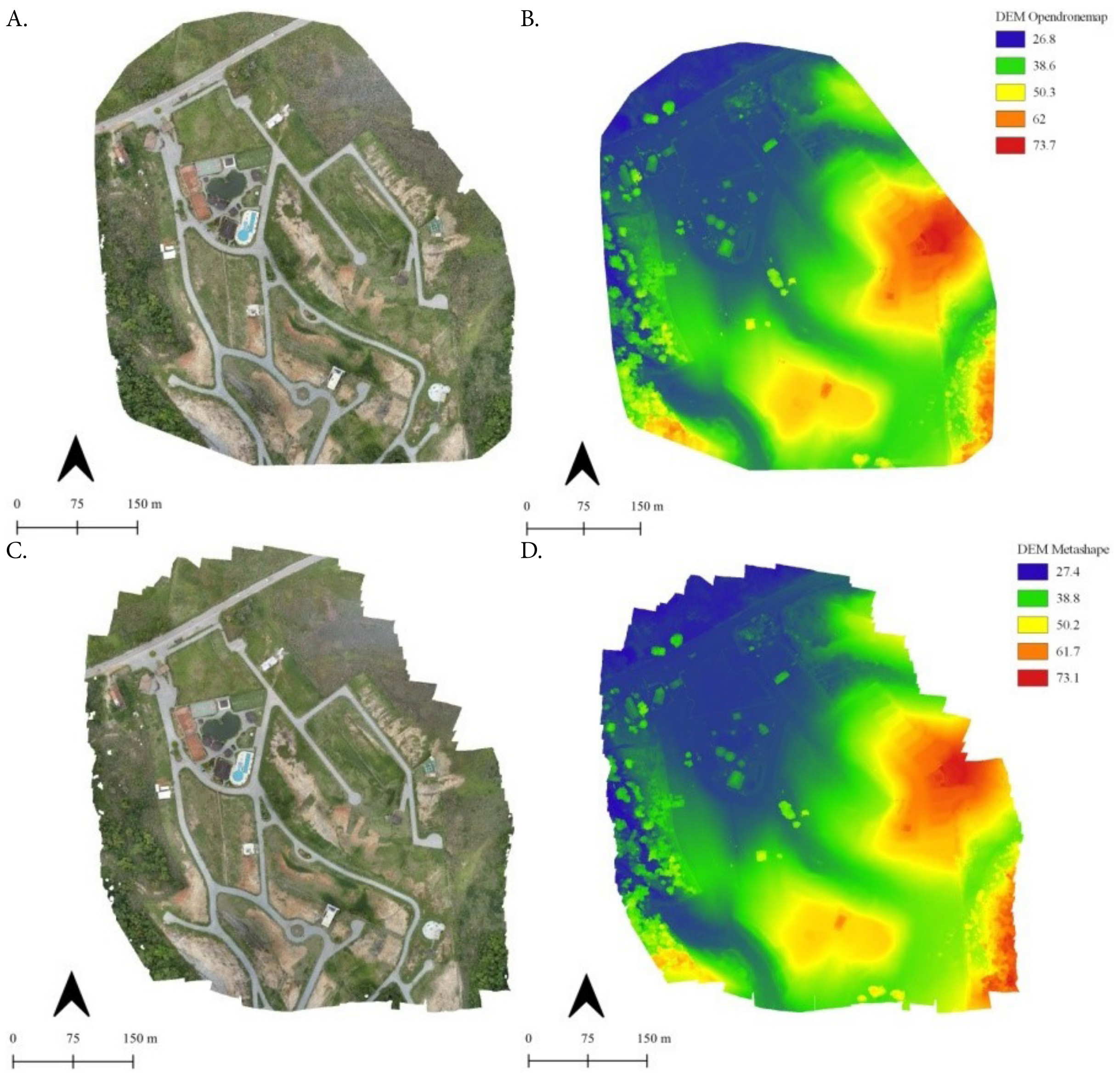


Figure 2. UAV image processing products generated by the Opendronemap (A) and (B) and Agisoft Metashape (C) and (D) software

al. (2018) states that precision may be overestimated when quantification uses only control points (GCPs) and not independent verification points (CPs).

In this way, the positional assessment based on the checkpoints is fundamental to obtaining planimetric and altimetric RMSE closer to the topographical reality. The exploratory analysis referring to calculating the distance differences between the photogrammetric targets marked in the image processed by the Opendronemap and Metashape software with the check-points (CPs) measured in the ground, can be observed in Table 3.

Table 3 showed planimetric and altimetric RMSE results much more discrepant than the values represented in Table 2. The statistics show the standard deviation value of the Z component corresponding to Opendronemap software, the smallest among the other components, and the closest to the mean value. The results of RMSE calculation of the X, Y and Z components compared to the recommended threshold in the standard ASPRS planimetric and altimetric positional accuracy document (Table 4) showed that the DEM generated by the Opendronemap software was the one with the best RMSE z result because the calculated value is lower than the table corresponding to Table b.7 of the ASPRS (2015) document for land with vegetation (DEM) ≤ 15 cm and GSD = 5 cm. However, Metashape provided a different RMSE z value from the tabulated value. These findings were then confirmed by the exploratory analysis (Table 3), which indicated very discrepant RMSE values in Z.

In the analysis of planimetric and altimetric RMSE using check-points, Villanueva & Blanco (2019) also pointed out a significant change in the errors corresponding to the amount of four CPs in image processing. It points out that the error value starts with approximately 4 m and becomes unstable from the implementing the tenth check-point until reaching centimeter precision.

Given the above, an unsatisfactory planimetric positional accuracy was observed for both software. Only the Opendronemap software resulted in a better altimetric RMSE value. The reason for this unexpected effect may lie in the number and distribution of control points, as well as in the photogrammetric targets established in the field.

Sanz-Ablanedo et al. (2018) demonstrated that the achieved accuracy concerning the geometric quality of photogrammetric surveys using drones depends on the local topography and number of GCPs used per unit area, an estimator that involves camera setup, photo overlay, and flight line orientation. The results obtained by the authors, indicated that the smallest number of GCPs generated an RMSE approximately 5-fold higher than the average GSD and that when more points were introduced, the RMSE value trend was twice that of the GSD.

Based on the analysis of several assessments concerning positional accuracy, Jiménez-Jiménez et al. (2021) indicate that control point distribution influences DEM accuracy, and that increasing the amount of GCPs can decrease accuracy when these points are not well distributed. Jaud et al. (2016) compared the RMSE values obtained by the Metashape and MicMac software using five GCPs. The z component result of the Metashape software was also unsatisfactory, but the authors managed to improve this by increasing the number of ground control points.

According to US ARMY (2002), the use of pre-signaled photogrammetric targets increases the accuracy of field measurements of control points and consequently, of the entire digital image processing. Also, it considers others important aspects in the planning and implementation of these targets, such as dimension, which must vary according to the scale of the aerial coverage, in this case the determined GSD, to allow a perfect identification in the photo. Also, the shape of the targets can be made in the shape of a cross, Y and T (Figure 3A), in a color that allows the appropriate contrast to the predominant color surroundings in the image. Candido et al. (2018) to facilitate the location of antenna points in the photos, also made markings on the floor, using white grout powder and graphite (Figure 3B) for greater contrast with the ground.

Table 3. Exploratory analysis of residual values observed in X, Y and Z, obtained by the Opendronemap and Agisoft Metashape software programs

Component	Maximum	Minimum	Mean	Standard deviation	Median	1st Quartile	3rd Quartile	RMSE
				Opendronemap (m)				
X	0.706	-0.460	0.028	0.541	-0.068	-0.380	0.339	0.470
Y	0.380	-0.483	0.033	0.372	0.118	-0.094	0.244	0.323
Z	0.303	0.032	0.166	0.135	0.165	0.061	0.270	0.041
XY (r)								0.570
				Metashape (m)				
X	0.288	-1.199	0.050	0.253	0.056	-0.151	0.257	0.225
Y	1.273	0.245	0.608	0.481	0.456	0.259	0.805	0.737
Z	1.525	0.210	0.959	0.579	1.051	0.668	1.342	1.171
XY(r)								0.771

RMSE - Root mean square error

Table 4. Results obtained for the evaluation of altimetric and planimetric positional accuracy according to ASPRS (2015)

Softwares	Planimetric accuracy – Orthophoto mosaic			Altimetric accuracy – DEM		
	GSD	RMSE r (calculated)	RMSE r (tabulated)	GSD	RMSE z (calculated)	RMSE z (tabulated)
Opendronemap	5 cm	57 cm	7.07 cm	5 cm	14 cm	15 cm
Metashape	24 cm	77 cm	38.9 cm	10 cm	117 cm	30 cm

RMSE r = RMSE xy; RMSE - Root mean square error; GSD – Ground sample distance

A.

B.

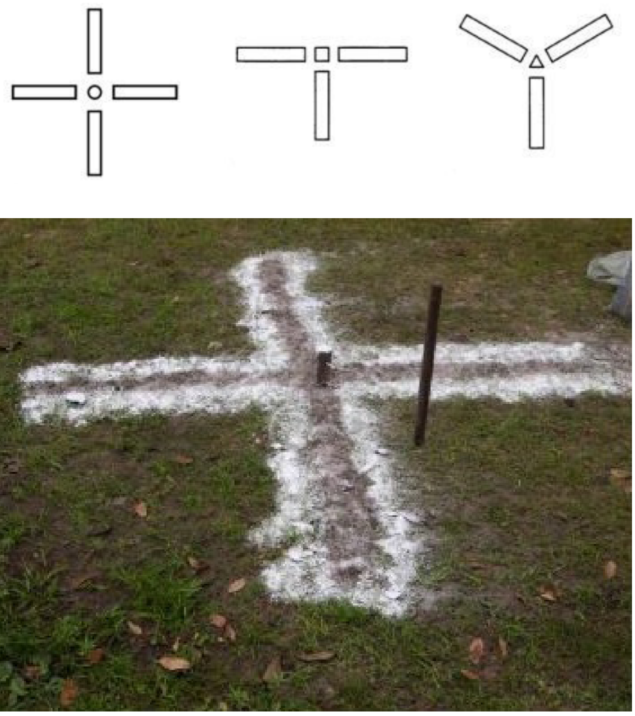


Figure 3. Targets in the shape of a cross, Y and T (A) and an example of ground marking to collect planimetric and altimetric control point

In the present study, lime was applied to mark the ground no size criteria (Figure 1B). The white color of this material caused powerful sunlight reflection, probably leading to geometric target distortions, making it difficult to establish the GCP alongside its photo correspondent, which is paramount in digital image processing.

The results obtained in the research regarding the quantity and distribution of field control points and verification points inserted in the digital processing of UAVs images conferred the impact caused by the planimetric and altimetric RMSE values. It is not an exaggeration to recommend a minimum of 20 field control points (ASPRS, 2015) to obtain adequate positional accuracy. It is essential to seek cost optimization but without sacrificing quality. Adequate process planning and control are paramount, whether concerning flight planning, field control point distribution and measurement and/or image acquisition and processing. These steps ensure the desired quality of the final product, allowing both image producers and users to understand the favorable or unfavorable mapping aspects and their applicability.

Conclusions

1. Orthophoto mosaic planimetric accuracy obtained from the two software is not acceptable according to current Accuracy Standards for Digital Geospatial Data. But it has potential for visualization and less accurate work, such as area recognition, environmental monitoring activities and plant species, and quantification of fauna and flora, among others.

2. The open-source software Opendronemap presented better altimetric accuracy according to the Accuracy Standards for Digital Geospatial Data. This, therefore, comprises a low-cost resource for UAV image processing able to meet technological teaching/research demands, mainly concerning public institutions.

3. The Opendronemap and Agisoft Metashape software can generate products displaying adequate precision for general mapping, as long as methodological recommendations based on previous assessments be respected according to the mapping purpose.

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