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Topographic mapping with remotely piloted aircraft for the purpose of georeferencing rural properties

Mapeamento topográfico com aeronave remotamente pilotada para fins de georreferenciamento de propriedades rurais

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Abstract: The goal of this study was to evaluate the quality of digital products obtained in topographic surveys using remotely piloted aircraft for the georeferencing of rural properties. The study was conducted at the Federal Institute of Education, Science, and Technology of Maranhão, São Raimundo das Mangabeiras Campus. Three areas with different terrain slopes were selected: 0 to 5%, 5 to 10%, and 10 to 20%. In each area, geodetic surveys were conducted using GNSS and aerial photogrammetry with a remotely piloted aircraft (at three flight altitudes: 70, 80, and 90 meters) to collect coordinates of photo-identifiable topographic points, totaling nine combinations of slope and flight altitude. Digital image processing was carried out using the Structure from Motion technique, resulting in orthomosaics and digital elevation models for each area/flight altitude as the final products. The generated images were evaluated according to the criteria established by the ABNT NBR 13.133/2021 Technical Standard and the Technical Manual for the Georeferencing of Rural Properties - 2nd Edition. It was possible to obtain digital products with high planimetric and altimetric positional accuracy when compared to similar studies found in the literature. It can be concluded that the flight altitude should be configured according to the terrain slope to be mapped. In areas with steeper slopes, it is recommended to conduct flights at lower altitudes to ensure greater planimetric accuracy of orthomosaics and digital elevation models.

Keywords: Planialtimetric Survey, Flight parameters, Accuracy assessment.

Resumo: O objetivo deste estudo foi avaliar a qualidade de produtos digitais obtidos em levantamentos topográficos com aeronave remotamente pilotada para fins de georreferenciamento de imóveis rurais. O estudo foi realizado no Instituto Federal de Educação, Ciência e Tecnologia do Maranhão, Campus São Raimundo das Mangabeiras. Foram selecionadas três áreas com diferentes declividades no terreno: 0 a 5%, 5 a 10% e 10 a 20%. Em cada área foram realizados levantamentos geodésicos com GNSS e aerofotogramétrico com aeronave remotamente pilotada (em três alturas de voo: 70, 80 e 90 m) para coletar as coordenadas de pontos topográficos foto identificáveis, totalizando nove combinações de declividade e altura de voo. O processamento digital das imagens foi realizado tendo como base a técnica *Structure from motion*, tendo como produto final o ortomosaico e o modelos digital de elevação de cada área/altura de voo. As imagens confeccionadas foram avaliadas conforme os critérios estabelecidos pela Norma Técnica ABNT NBR 13.133/2021 e pelo Manual Técnico para o Georreferenciamento de Imóveis Rurais – 2ª Edição. Foi possível obter produtos digitais com alta precisão posicional planialtimétrica quando comparada a trabalhos similares encontrados na literatura. Pode-se concluir que a altura de voo deve ser configurada de acordo com a declividade do terreno a ser mapeado. Em áreas com maior declividade recomenda-se que os voos sejam realizados em alturas menores para garantir uma maior precisão planialtimétrica dos ortomosaicos e dos modelos digitais de elevação.

Palavras-chave: Levantamento planialtimétrico, Parâmetros de voo, Avaliação da precisão.

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1. Introduction

The use of near-range aerial photogrammetry for topographic purposes has increased notably during the last decade due to the improved availability of more efficient digital imaging systems, along with the advancement of easier techniques for digital image processing (DIP) (SADEQ, 2019).

Topographic data are widely used as great support information in various areas of research and civil applications such as environmental management, agriculture, and land regulation (PIJL et al., 2020), in addition to being an indispensable tool in most agricultural experiments. The gathering of topographic data, however, has always been a relatively slow activity, requiring a high degree of technical knowledge and costly.

Seeking a solution to this problem, the use of Remotely Piloted Aircraft (RPA) for the gathering of geographic data was initiated. The first recorded commercial use of an RPA was in the early 1980s in Japan, when it was used to apply pesticides to rice farms, however the technology for the time was expensive and very heavy (WONZOSKI & OLIVEIRA, 2020).

RPAs are very efficient equipment in the acquisition of large-scale cartographic and geospatial data, which can be used to generate various products in the various fields of sciences, such as digital surface models (DSM), orthophotos, 3D models of buildings, topographic maps, planimetric features and quantitative surveying, among others. These products are crucial in different areas, such as topographic mapping, urban and rural planning, management of agricultural activities, modeling of environmental phenomena, among others (COLOMINA & MOLINA, 2014; OLLERO, 2015).

The modernization of remote sensing techniques for topography has made it possible for topographic data obtained by aerial photogrammetry with RPAs to be increasingly accessible and accurate (SILVA et al., 2022). In order for this data to be accurate, a series of configurations and methodologies need to be applied, such as flight height, GSD size, flight speed, percentage of image overlap, number and location of control points, among others.

The main topographic products of a survey done using aerial photogrammetry are orthophotos and digital terrain and elevation models. These products are generated based on the SFM (structure from motion) technique, which is an image processing technique used to reconstruct three-dimensional structures from sequences of two-dimensional images collected on moving sensors (JIANG et al., 2020).

Any image obtained through the SFM technique can have georeferenced coordinates in a geographic reference system. This can be done through the location data recorded by the RPAs in the metadata of the images, which have sensors with a Global Positioning System (GPS) for navigation with low topographic accuracy, as well as with the insertion of photo-identifiable reference points with previously known geographic coordinates in the area to be surveyed, called control points (PC) (SANZ-ABLANEDO et al. 2018).

In order for the digital products obtained in topographic works with RPAs to be used in the georeferencing of rural properties, a series of accuracy standards must be respected. In Brazil, the National Institute of Colonization and Agrarian Reform (INCRA) published in 2022 the Technical Manual for the Georeferencing of Rural Properties – 2nd Edition (INCRA, 2022), which cites the criteria that must be met when using aerial photogrammetry for the purpose of georeferencing rural properties.

Observing the importance of incorporating new technologies in data surveys by different professionals in the exact sciences, the objective of this study was to evaluate the quality of digital products obtained in topographic surveys with remotely piloted aircraft for the purpose of georeferencing rural properties.

2. Methodology

The study was done at the Federal Institute of Education, Science and Technology of Maranhão, São Raimundo das Mangabeiras Campus, within the scope of the research group GECEM - Study Group in Geotechnology of the Cerrado Maranhense. Three areas were selected on a rural property, with different slopes on the terrain to be used as experimental areas: 0 to 5%, 5 to 10% and 10 to 20% slope, as shown in Figure 1.

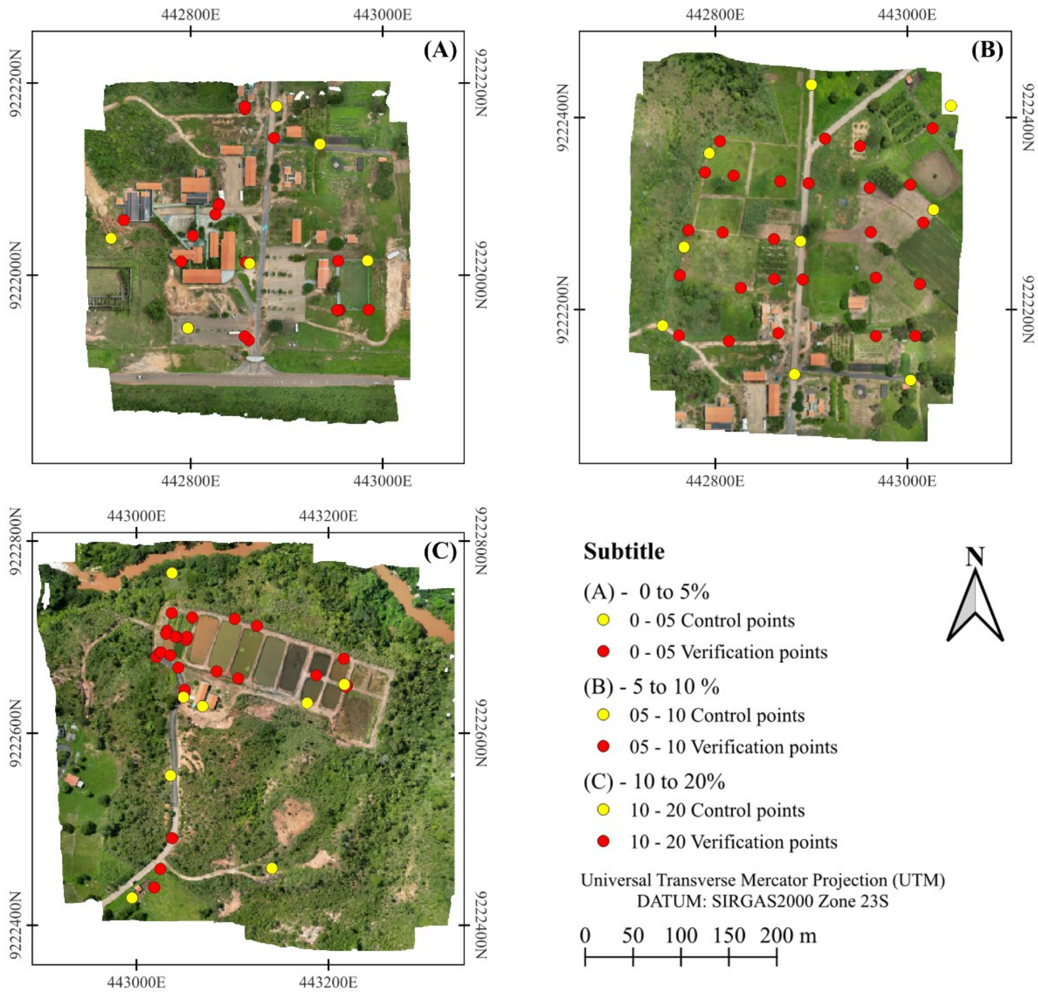

Figure 1 – Study area with geographical distribution of control and verification points. (A) – 0 to 5% slope, (B) – 5 to 10% slope, (C) – 10 to 20% slope.
Source: Authors (2024).

After selecting the experimental areas, geodetic surveys were performed in accordance with the Brazilian Association of Technical Standards (ABNT) NBR 13.133/2021, which deals with the procedures inherent to topographic surveys (ABNT, 2021). This step consisted of collecting the geographic coordinates of photo-identifiable locations, then they were divided into control points (PCs) and verification points (PVs). The PCs were used to define the relationship between the coordinate systems of the image and the coordinate systems of the terrain (georeferencing of the image). Regarding the PVs, it was used in the statistical verification of the accuracy of the generated products. The data obtained from the geodetic surveys were applied as a reference standard in the evaluation of the results.

A pair of devices embedded with the Global Navigation Satellite System (GNSS) identified by the FOIF A30 model was used, with an accuracy of 10 mm + 1 ppm horizontally and 20 mm + 1 ppm vertically, in RTK (Real-Time Kinematic) mode. A reference point was installed at a central location in the experimental area, and these data were processed through the Precise Point Positioning technique by the IBGE-PPP platform - Online service for post-processing of GNSS data, which processes GNSS data collected by receivers to obtain coordinates referenced to SIRGAS 2000 (Geocentric Reference System for the Americas) (IBGE, 2021). Based on the precise coordinates of the base provided by the platform, the coordinates collected from all points of the survey were corrected.

All collected points (GPC and PV) were marked on the ground with white paint/powdered plaster to facilitate photoidentification during the DIP.

Then, aerial photogrammetric surveys were done using a DJI multirotor remotely piloted aircraft (RPA), model Mavic Air 2S. The specifications of the RPA used are presented in Table 1. In each experimental area (0 to 5%, 5 to 10% and 10 to 20%) three surveys were performed, differing from each other in flight height: 70, 80 and 90 meters, respectively, totaling nine combinations.

Table 1 – Specifications of the remotely piloted aircraft used in the study.

Attributes	Specifications	Image
Brand	DJI	
Model	AIR 2S	
Takeoff weight	595 g	
Open Dimensions	183×253×77 mm	
Max. flight time (no wind)	31 minutes	
Max. flight distance (no wind)	18.5 km	
Max. flight speed	19 m/s (S mode) / 15 m/s (N mode) / 5 m/s (C mode)	
Operating temperature range	0° to 40°C	
Operating frequencies	2.4 GHz - 5.8 GHz	
GNSS	GPS+GLONASS+GALILEO	
Sensor	1" CMOS	
Effective pixels	20 MP; 2.4 µm pixel dimensions	
Aperture	f/2.8	
Image size	20 MP; 5472×3648 (3:2); 5472×3078 (16:9)	
Stabilization	Triaxial (pitch, swivel, swivel)	

Source: Manufacturer's website (https://www.dji.com/br/support/product/air-2s).

The flights were planned with the Drone Harmony mobile software, speed of 8 m $^{s-1}$ and 80% lateral and longitudinal overlap. The survey areas were delimited in order to collect all the topographic points (PC and PV) implanted throughout the perimeter of the study area.

Digital image processing (DIP) was done based on the SFM technique, which is an image processing technique used to reconstruct three-dimensional structures from sequences of two-dimensional images collected from moving sensors (JIANG et al., 2020).

The preparation of topographic products through the DIP followed the ensuing workflow: adding photos, aligning photos, pointing out PCs, realigning photos, generating a dense point cloud, generating and exporting a digital elevation model (DEM) and finally, generating and exporting orthophotos. At the end of the DIP, the orthomosaic and the DEM of each area/flight height were exported for further analysis.

A computer with the following hardware configuration was used for image processing: Intel Core i5-8265U 1.6GHz processor with 4 processing cores and 8 Threads; 240 Gb SSD and 1Tb HDD storage units; NVIDIA graphics card GeForce RTX 3050 model with 4 Gb; and 8 Gb RAM.

After exporting the digital products, the free software QGIS® 3.28 was used to extract the X and Y coordinates of the orthophotos and Z (altimetry) of the DEMs from the verification points of each treatment evaluated. Then, the positional discrepancies of the PV coordinates between the data collected in the geodetic survey and the data extracted from the generated digital products (orthomoisac and DEM) of each slope/height combination were calculated, for subsequent calculation of mean square errors (RMSE), according to Equations 1 to 4 proposed by 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 $RMSE_z$ - mean square errors of the X, Y and Z coordinates, respectively;
$RMSE_r$ - mean square error in the horizontal plane;
xc_i, yc_i and zc_i - coordinates of the PVs marked in the images;
xv_i, yv_i and zv_i - coordinates of the PV collected by GNSS;
n - number of verification points tested;
i - integer number ranging from 1 to n.

The GeoPEC 3.5.2 software (SANTOS, 2023) was used to evaluate the positional accuracy standard of the products generated according to current legislation. For the planialtimetric evaluation of the products generated, the criteria established in Technical Standard ABNT NBR 13.133/2021 - Executing a topographic survey - Procedure, which establishes that the precision experiments performed must ensure that the calculated discrepancy meets the tolerance established for the study, which is three times the desired precision, and a planimetric and/or altimetric topographic survey must be considered accepted if 90% of the points of verification of accuracy meet the considered tolerance. In this study, a desired planialtimetric precision of 0.3 m was considered.

To assess whether the resulting products can be used in georeferencing work of rural properties, the criteria established by the Technical Manual for the Georeferencing of Rural Properties – 2nd Edition (INCRA, 2022) were used, and the tests were done considering a scale of 1/1000:

a) The Ground Sample Distance - GSD must be compatible with the feature to be identified, and the precision of the type of limit to be represented must be respected;
b) Use of check/verification points, respecting the proportionality of the area, geometry and relief, aiming to meet the Cartographic Accuracy Standard for Digital Cartographic Products (PEC/PCD), according to the Technical Specification for Geospatial Data Quality Control (ET-CQDG) and Technical Specification for Vector Geospatial Data Acquisition ET-ADGV, both from the Army Geographic Service Directorate;
c) The class resulting from the calculation of the PEC must be adequate to the precision required for the type of limit that is to be represented;
d) If control points are used, they should not be used as checkpoints;
e) For vertices whose coordinates are determined by aerial photogrammetry, the positional precision values will be the Root Mean Square (RMS) values obtained in the process of evaluating positional accuracy.

3. Results and discussion

From the results obtained and described in Table 2, it can be observed that the digital products generated (orthomosaic and DEM) presented high values of topographic precision in all the flights evaluated. It was also observed that in all the terrain slopes evaluated, the flights with higher height (90 m) presented higher values of mean square errors (RMSE) of the Z coordinate and the horizontal distance (H), although small, these variations can negatively interfere with the final quality of the digital product.

Table 2 – Mean square errors (RMSE) of the coordinates X, Y, Z, and the horizontal distance (H) of digital cartographic products obtained by remotely piloted aircraft in areas with different slopes, with images collected at different flight heights.

Slope	Flight height	RMSE (m)			
		X	Y	Z	H
0-5%	70 m	0.11	0.12	0.34	0.17

	80 m	0.11	0.17	0.56	0.20
	90 m	0.23	0.16	0.60	0.28
5-10%	70 m	0.41	0.35	0.69	0.53
	80 m	0.36	0.30	0.49	0.47
	90 m	0.48	0.29	1.17	0.56
10-20%	70 m	0.12	0.11	0.27	0.16
	80 m	0.20	0.16	0.27	0.25
	90 m	0.27	0.18	0.43	0.33

Source: Authors (2024).

According to the results obtained in this study, high precision of the orthomosaics and DEMs produced is suggested, given that the RMSE values observed were relatively low when compared to other similar studies in the literature.

Fonseca Neto et al. (2017) observed a mean discrepancy of 0.163 m, with an RMSE of 0.186 m when using the same methodology to evaluate the planimetric positional accuracy of an orthomosaic generated from a sensor embedded in an RPA platform of the same model as the one used in this study. Vitti et al. (2018), RMSE values higher than 0.375 m, with a maximum value of 0.514 m, were verified when evaluating the accuracy of image mosaics obtained with RPA with different image acquisition sensors. Liu et al. (2018) and Gómez-Candón et al. (2014) obtained RMSE results in millimetric order, indicating the feasibility of using this product in high-precision applications.

The results generated from the determination of the horizontal point-to-point discrepancies are presented in Figure 2.

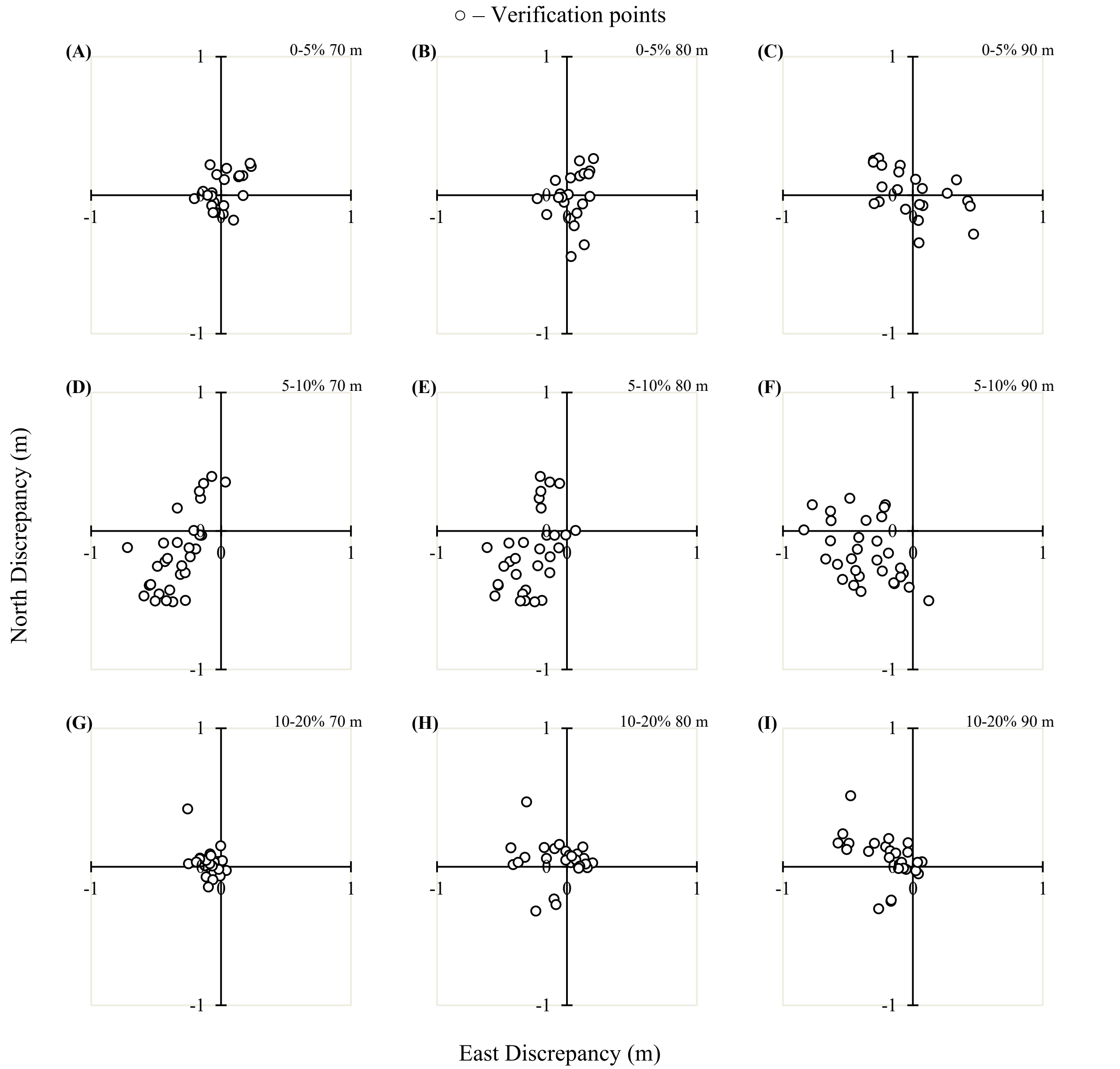

Figure 2 – Planimetric positional discrepancy of digital cartographic products obtained by remotely piloted aircraft in areas with different slopes, with images collected at different flight heights. 0-5%: (A) – 70 m, (B) – 80 m, (C) – 90 m; 5-10%: (D) – 70 m, (E) – 80 m, (F) – 90 m; 10-20%: (G) – 70 m, (H) – 80 m, (I) – 90 m.
Source: Authors (2024).

It was possible to observe the values of planimetric positional discrepancies in the north and east planes, in addition to a small dispersion of the discrepancies in all the flights performed. Average values of discrepancies in the north and east planes of less than 1.0 m were obtained in all the flights evaluated, as previously seen in Figure 2, and the greatest discrepancies were observed in the flights performed in the area with 5 to 10% of slope (Figures 2D, 2E and 2F), with a greater dispersion of the points in the southwest quadrant, at all flight heights.

In those situations, with a slope of 0 to 5%, illustrated in Figures 2A, 2B and 2C, the dispersion was standard in all quadrants. In the slopes ranging from 10 to 20%, contemplated by Figures 2G, 2H and 2I, there was a standard dispersion in the flights performed at 70 and 80 meters of altitude, resulting in a dispersion in the northwest quadrant in the flight performed at 90 meters of altitude.

These results may be related to the climatic conditions at the time of the aerial photogrammetric survey, given that several authors report that several environmental factors affect the quality of the products, including wind speed and direction (SANZ-ABLANEDO et al., 2018).

Figure 3 shows the detailed cut-outs of the precision of PVs in the orthomosaics made. Such results corroborate the planimetric precision observed in the results mentioned above. Positional differences in PV were observed between orthomosaics made with images obtained at different flight heights, in areas with similar slopes.

The variability of the results is potentially vulnerable to climatic conditions during the period of image collection, considering that climatic factors directly interfere with the quality of the GPS signal captured by the electronic module of the RPA, such as cloudiness of the day and atmospheric pressure (SANZ-ABLANEDO et al., 2018).

According to Oliveira and Brito (2019) and complementing Sanz-Ablanedo et al. (2018), other parameters that directly influence the quality of the images are the incidence of wind gusts that end up compromising the stability of the RPA and also the quality of the onboard camera. Guimarães et al. (2023) state that distortion errors in the images directly impact the elaboration of orthomosaics, as they are common and, when present, negatively influence the final quality of the products generated, but that they can be minimized when they adopt a significant amount and distribution of PCs throughout the area to be surveyed.

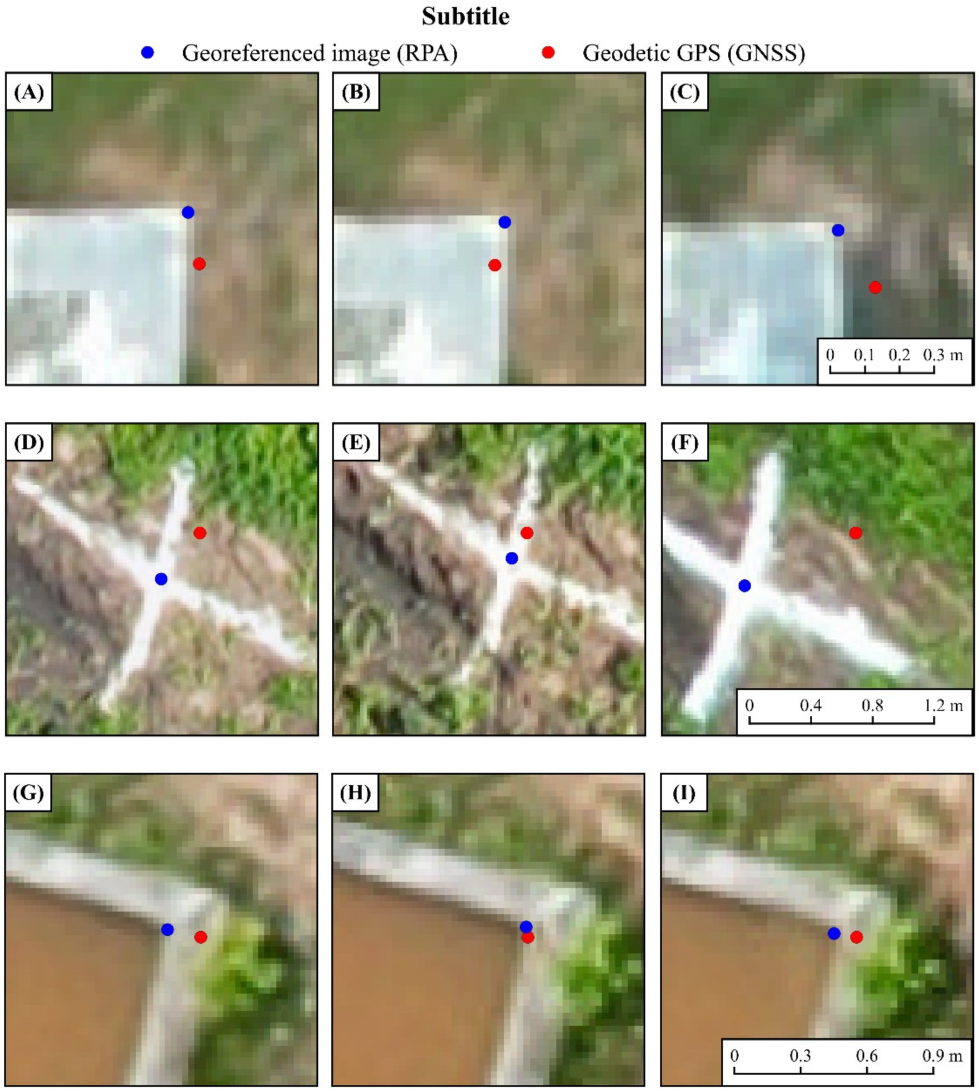

Figure 3 – Details of the planimetric accuracy of digital cartographic products obtained by remotely piloted aircraft in areas with different slopes, with images collected at different flight heights. 0-5%: (A) – 70 m, (B) – 80 m, (C) – 90 m; 5-10%: (D) – 70 m, (E) – 80 m, (F) – 90 m; 10-20%: (G) – 70 m, (H) – 80 m, (I) – 90 m.
Source: Authors (2024).

Figure 4 shows the DEMs produced through image processing with the SFM technique. The data presented in the figure emphasizes the differences in slope between the areas evaluated in this study. It can be observed that, visually, it is not possible to evaluate the altimetric accuracy of the digital products made.

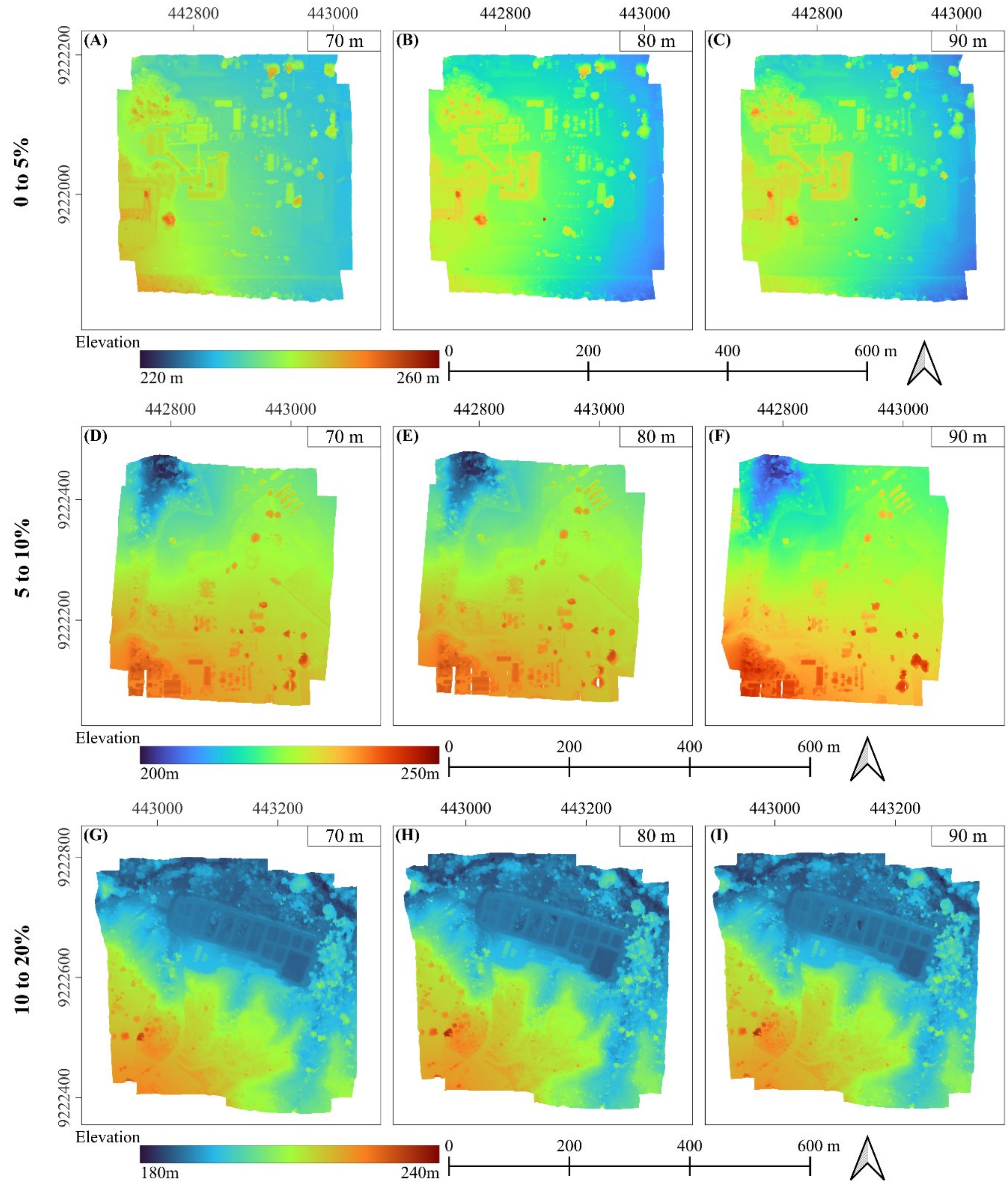

Figure 4 – Digital elevation models produced with images obtained by remotely piloted aircraft in areas with different slopes, with images collected at different flight heights. 0-5%: (A) – 70 m, (B) – 80 m, (C) – 90 m; 5-10%: (D) – 70 m, (E) – 80 m, (F) – 90 m; 10-20%: (G) – 70 m, (H) – 80 m, (I) – 90 m.
Source: Authors (2024).

When the discrepancies of the point-to-point Z altimetric coordinate were evaluated, the presence of significant variations between the evaluated areas could be observed. In general, an increase in the mean discrepancy (ΔZ) can be observed with the increase in the RPA flight height in all areas evaluated (Figure 5).

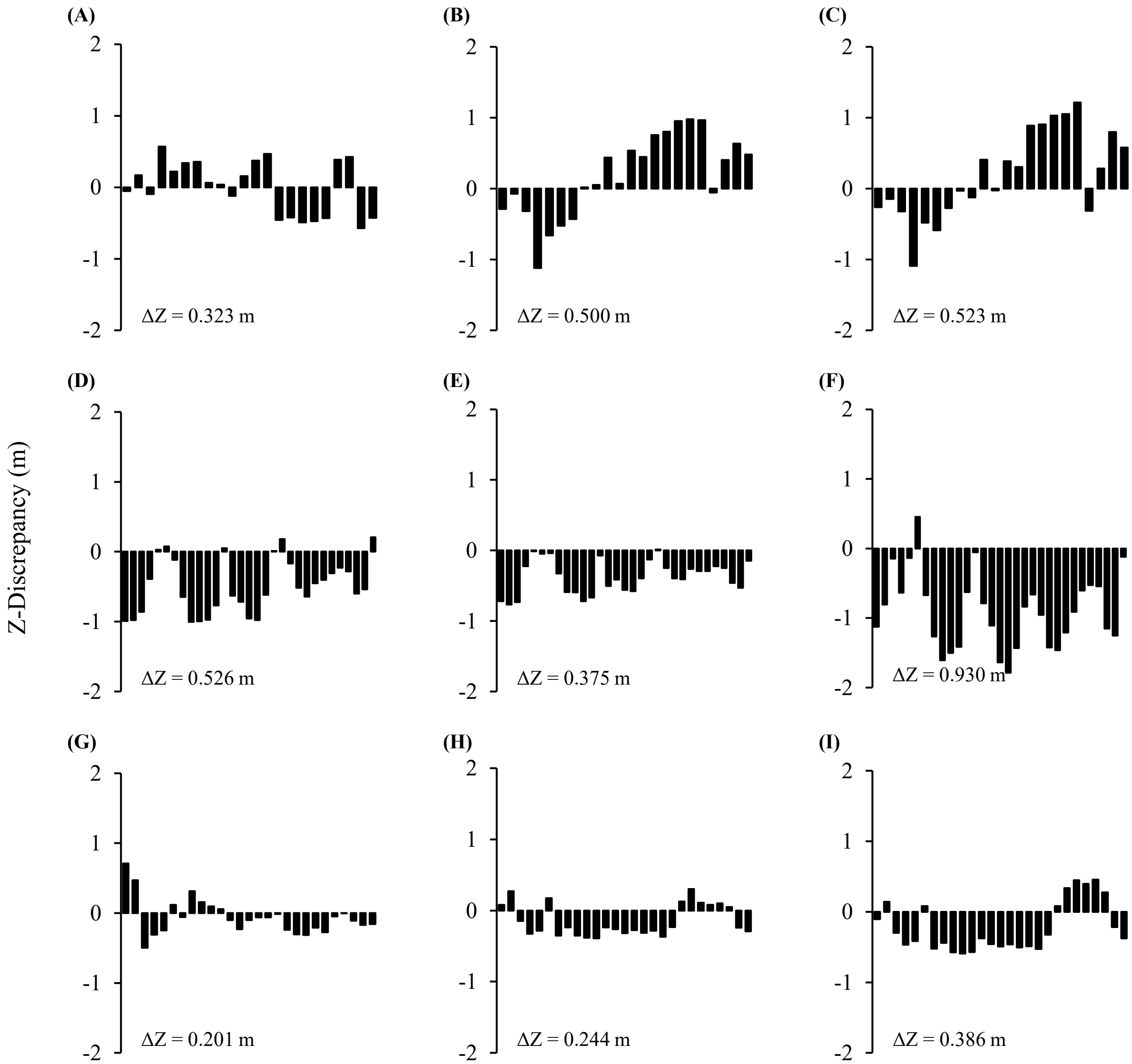

Figure 5 – Altimetric positional discrepancy of digital cartographic products obtained by remotely piloted aircraft in areas with different slopes, with images collected at different flight heights. 0-5%: (A) – 70 m, (B) – 80 m, (C) – 90 m; 5-10%: (D) – 70 m, (E) – 80 m, (F) – 90 m; 10-20%: (G) – 70 m, (H) – 80 m, (I) – 90 m.
Source: Authors (2024).

Based on the results presented previously, it can be inferred that the flight height directly interfered with the altimetric accuracy of the digital products made through the processing of the images captured by RPA. Based on the principles of stereoscopy, associated with the principles of the SFM processing technique, the operator must plan the collection of images in order to obtain the best relationship between the parameters of flight height and overlapping of the images, in order to obtain the largest number of images from the same point of the survey, given that the greater the number of points of view, the more representative the three-dimensional reconstruction. These results corroborate the observations reported by Jiang et al. (2020), which detail all the stages of image processing through the SFM technique, where they report that the distance from the mapped target will directly interfere in the three-dimensional reconstruction of the studied area, and consequently, in the altimetric accuracy of the digital products generated.

The interference of flight height in the altimetric accuracy of topographic products obtained with RPAs has been widely studied in the literature by several authors, who report different behaviors in different situations. Anders et al. (2020) evaluated the altimetric accuracy of DEMs made with images obtained with RPAs at different flight heights and found that flight height provided increases in vertical discrepancy. Udin and Ahmad (2014) evaluated the planialtimetric accuracy of products obtained with images captured by RPA at flight heights ranging from 40 to 100 m in height and found a positive linear correlation between flight height and RMSE. These results corroborate the data obtained in this study. However, studies done by other authors state that the flight height does not have a significant influence on the altimetric accuracy of these products (Santana et al., 2021; Brookman-Amissah et al., 2022).

The evaluation of the accuracy of the products generated in relation to the Technical Standard ABNT NBR 13.133/2021 – Executing a topographic survey - Procedure (ABNT, 2021), presented in Table 3.

Table 3 – Classification of digital products (orthomosaics and DEMs) generated according to Technical Standard ABNT NBR 13.133/2021 - Executing a topographic survey - Procedure, with desired accuracy of 0.33 m.

Slope	Flight height	Planimetry (orthomosaic)		Altimetry (DEM)	
		% Δd ≤ Tolerance	Decision	% ΔZ ≤ Tolerance	Decision
0-5%	70 m	100	Approved	100	Approved
	80 m	100	Approved	95.5	Approved
	90 m	100	Approved	81.8	Failed
5-10%	70 m	96.8	Approved	93.5	Approved
	80 m	93.5	Approved	100	Approved
	90 m	100	Approved	54.8	Failed
10-20%	70 m	100	Approved	100	Approved
	80 m	100	Approved	100	Approved
	90 m	100	Approved	100	Approved

Source: Authors (2024).

It can be seen that all the orthomosaics made were approved by using a desired precision of 0.33 m. According to NBR 13.133/2021, the tolerance limit is considered to be up to three times the desired accuracy. Therefore, when approved by the NBR, it is inferred that more than 90% of the PVs evaluated obtained a discrepancy of less than 0.99 m.

It should be noted that NBR 13.133/2021 does not specify which precision value should be used to assess the accuracy of the products, it only states that in order to be accepted, a topographic survey must present 90% of the points subject to the inspection within the defined tolerance. Therefore, the choice of the desired precision value will directly influence the result of the classification. Thus, when working with digital products generated by aerial photogrammetry, it is recommended that the chosen precision value should be compatible with the GSD of the image, as well as the features that will be identified.

When the altimetric products were evaluated, it was found that when the flight height was increased to 90 meters in areas with 0 to 5 and 5 to 10% slope, the DEMs failed under NBR 13.133/2021. Such behavior was not repeated in the area with 10 to 20% of slope, and this DEM was considered as approved. However, even though it was considered approved, higher ΔZ values were observed when collecting images at a height of 90 meters, when compared to flights at 70 and 80 meters in the same area (Figure 4). These results corroborate the interference of flight height in the altimetric accuracy of digital products.

When evaluating the precision criteria established by INCRA to use aerial photogrammetry for the purpose of georeferencing properties in rural environments, it was observed that all the orthomosaics made in this study met the criteria established by INCRA and can be used in georeferencing works of rural properties with a scale of 1/1000 or lower, as described in Table 4.

Table 4 – Classification of the orthomosaics generated in relation to the Technical Manual for the Georeferencing of Rural Properties – 2nd Edition (INCRA, 2022).

Slope	Flight height	ET-CQDG Decree	Boundary Type	INCRA Precision
0-5%	70 m	CLASS B	Artificial	Fulfilled
	80 m	CLASS B	Artificial	Fulfilled
	90 m	CLASS B	Artificial	Fulfilled
5-10%	70 m	CLASS C	Natural	Fulfilled
	80 m	CLASS C	Natural	Fulfilled
	90 m	CLASS D	Natural	Fulfilled
10-20%	70 m	CLASS A	Artificial	Fulfilled
	80 m	CLASS B	Artificial	Fulfilled
	90 m	CLASS C	Natural	Fulfilled

Source: Authors (2024).

These results demonstrate the high quality of the products generated, since, in the evaluation of accuracy according to the criteria established by INCRA (2022), the 1/1000 scale has a discrepancy limit of 1.0 m (ET-CQDG Class D), that is, there is a requirement that 100% of the discrepancies present values less than 1 meter.

Based on the results obtained in this study, it can be concluded that the flight height should be configured according to the slope of the terrain to be mapped. It was observed that only in the area with a slope of 0 to 5%, there was no reduction in the accuracy of the orthomosaics with the increase in flight height, and all orthomosaics were classified as Class B according to Decree ET-CQDG (DSG, 2016), with 100% of the discrepancies less than 0.5 m, regardless of the flight height.

In areas with slopes of 5 to 10% and 10 to 20%, there was a significant reduction in accuracy when flights were made at higher heights. In the flights done at 70 and 80 meters in height, in the area with slopes ranging between 5 and 10%, the calculated discrepancies reached values of up to 0.8 m. In the flight performed at 90 meters, values of up to 1.0 m of discrepancy were recorded.

In the area with slope ranging from 10 to 20% of slope, there was a gradual reduction in the accuracy of the orthomosaic with the increase in flight height. The orthomosaic made with images obtained at a height of 70 meters was classified as Class A, with discrepancies of less than 0.28 m. When flying at 80 meters, the orthomosaic presented discrepancies of less than 0.5 m, falling into Class B. Orthomosaic with images at 90 meters was classified as Class C, with discrepancy values of up to 0.8 m.

The classification of the images according to the parameters made available in the Decree ET-CQDG (DSG, 2016), used by INCRA as evaluation criteria for digital products with the objective of georeferencing rural properties, classifies the products based on the values of average discrepancies obtained in the evaluation of accuracy, considering the classification of the type of landmark, defined by INCRA in the Technical Manual for the Georeferencing of Rural Properties – 2nd Edition (INCRA, 2022), can help professionals in the use of digital products.

Considering a scale of 1/1000, Class A of the ET-CQDG has a discrepancy limit of 0.28 m, while Class B has 0.5 m. These two classes are the most demanding in terms of precision, which can be used to map artificial boundary vertices, such as fences, walls, roads, ditches, canals, among others (INCRA, 2022). Classes C and D allow discrepancy limits of 0.8 and 1.0 m, respectively. Products classified in these classes have potential use in mapping that involve only borderline vertices of the natural type and/or inaccessible, for example, bodies of water or watercourses, ridge lines, grottos, slope crests, among others (INCRA, 2022).

In the work developed by Guimarães et al. (2023), the planimetric accuracy of an orthomosaic originated from RPA was analyzed and average discrepancy values of approximately 0.121 m were reached, consequently categorized in Class A, thus meeting the technical requirements proposed by INCRA in the development of surveys involving the georeferencing of rural and even urban properties.

In order to obtain digital products from aerial photogrammetric surveys performed by RPA with positional quality, several factors must be considered, ranging from the characteristics of the area to be mapped, such as slope and land coverage; flight planning parameters, such as flight speed and height, and configured overlay; climatic conditions at the time of operation, such as wind speed and luminosity (SANZ-ABLANEDO et al., 2018), to the digital processing of the images, including the quality of the point cloud generated during the process (SAI et al., 2019; LIU et al., 2018). The results obtained in this study indicate that the flight height at the time of image acquisition interferes with the planialtimetric quality of orthomosaics and DEMs made with images obtained with RPAs. In this sense, it is recommended that as the slope of the terrain increases, the flight height is reduced in order to obtain products with superior positional quality.

4. Final considerations

In this study, the planialtimetric accuracies of orthomosaics and digital elevation models (DEM) produced with images obtained by remotely piloted aircraft were evaluated. The images were collected at three different flight heights (70, 80 and 90 m), in three areas with different slopes (0 to 5%, 5 to 10% and 10 to 20%). According to the methodology used, and from the results obtained, it was possible to obtain digital products with high planialtimetric positional accuracy when compared to similar studies found in the literature.

It was possible to observe a reduction in the planimetric precision of the orthomosaics and altimetric precision of the DEMs with the increase in the flight height in the evaluated areas, concluding that this parameter should be configured according to the slope of the terrain to be mapped. In areas with greater slope or rugged topographic conditions, it is recommended that flights be performed at lower heights to ensure greater planialtimetric accuracy. The application of evaluation parameters provided for in the Technical Manual for the Georeferencing of Rural Properties – 2nd Edition in rural and/or mixed-use properties is important to guide the studies of application of aerial photogrammetry in these types of properties.

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