

Analysis of the Accuracy of Orthophotos Generated by UAS with RTK Sensors for Application in Urban Land Regularization (REURB)

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Key words: UAS, Photogrammetry, Land Cadastre, REURB.

SUMMARY

Unplanned urban occupation has increasingly required public authorities to establish land-use planning policies. Article 182 of the 1988 Federal Constitution determines that urban policy must guarantee the social functions of the city and ensure the well-being of its inhabitants. Based on this principle, several laws have been enacted, including Law No. 10,931/2004 (extrajudicial area rectification), Law No. 13,105/2015 (extrajudicial adverse possession), and mainly Law No. 13,465/2017, which created the Urban Land Regularization (REURB). Originating from Provisional Measure No. 759/2016, this law expanded the demand for geospatial data and technologies, requiring municipalities to perform georeferenced topographic and cadastral surveys. According to Decree No. 9,310/2018, property boundary coordinates must present a positional error below 8 cm. Although remote sensing surveys using satellites, aircraft, or RPAs (Remotely Piloted Aircraft) are increasingly applied in cadastral development, current Brazilian standards such as ABNT NBR 13133:2021 and ABNT NBR 17047:2022 do not specifically regulate three-dimensional surveys for regularization purposes. Meanwhile, aerial photogrammetry with UAS has gained prominence due to advances in GNSS positioning (RTK, Network RTK, and PPK), enabling high accuracy even with limited ground control points. These technologies reduce costs and optimize operations, yet regulations still lack criteria for evaluating the accuracy of orthophotos generated by drones. The geometric reliability of orthophotos depends on parameters such as ground sample distance (GSD), flight altitude, and flight planning (overlaps and oblique images). These factors directly influence parcel boundary interpretation and the legal security of cadastral data. In this context, the present study proposes a comparative analysis of orthophotos generated with different flight configurations using the DJI M3M (Matrice 3 Enterprise) with RTK. Four products were created: (1) 1 cm GSD with longitudinal flight; (2) 2 cm GSD longitudinal; (3) 5 cm GSD longitudinal; and (4) 2 cm GSD cross-flight with oblique images (-60°). Checkpoints surveyed with a geodetic GNSS receiver will be used to assess positional accuracy. Parcel boundaries will be extracted from each orthophoto, and the coordinates of vertices compared to one another and to field measurements. The objective is to evaluate the geometric accuracy of photogrammetric products and identify the operational conditions under which they comply with legal requirements for REURB. This research contributes to defining feasible technical parameters for the reliable use of RPAs in urban land regularization processes in Brazil.

Palavras-chave: UAS, Fotogrametria, Cadastro Territorial, REURB.

RESUMO

A ocupação urbana desordenada tem exigido cada vez mais do poder público a formulação de políticas de ordenamento territorial. O Artigo 182 da Constituição Federal de 1988 determina que a política urbana deve garantir as funções sociais da cidade e assegurar o bem-estar dos habitantes. Com base nesse princípio, foram instituídas diversas leis, como a nº 10.931/2004 (retificação extrajudicial de área), nº 13.105/2015 (usucapião extrajudicial) e, principalmente, a nº 13.465/2017, que criou a Regularização Fundiária Urbana (REURB). Originada da Medida Provisória nº 759/2016, essa lei ampliou a demanda por dados geoespaciais e tecnologias, exigindo que municípios realizem levantamentos topográficos e cadastrais georreferenciados. O Decreto nº 9.310/2018, que a regulamenta, estabelece que os vértices de imóveis devem apresentar erro posicional esférico inferior a 8 cm. Embora levantamentos tridimensionais com sensores remotos — satélites, aeronaves ou UAS (Sistema de Aeronave Não Tripulada) — já sejam empregados em cadastros territoriais, normas como a ABNT NBR 13133:2021 e a ABNT NBR 17047:2022 ainda não regulamentam seu uso específico para fins de regularização fundiária. Nesse cenário, a fotogrametria aérea com UAS ganhou destaque, impulsionada pelo avanço de sensores GNSS de alta precisão e métodos como RTK, RTK em rede (NTRIP) e PPK, que permitem resultados confiáveis mesmo com poucos pontos de apoio em campo. Essas tecnologias reduzem custos, otimizam recursos e aumentam a eficiência, mas ainda não há critérios normativos claros para avaliar a acurácia de ortofotos obtidas por drones para estes fins. A qualidade geométrica dessas ortofotos é influenciada por parâmetros operacionais, como a distância de amostragem no solo (GSD), altitude de voo e planejamento (sobreposições e imagens oblíquas). Esses fatores afetam diretamente a identificação de limites de parcelas e, conseqüentemente, a segurança jurídica dos dados cadastrais. Nesse contexto, o presente estudo propõe uma análise comparativa de ortofotos geradas em diferentes configurações de voo com o drone DJI M3M (Matrice 3 Enterprise) equipado com RTK. Foram produzidos quatro produtos: (1) 1 cm GSD com voo longitudinal; (2) 2 cm GSD longitudinal; (3) 5 cm GSD longitudinal; e (4) 2 cm GSD com voo cruzado e imagens oblíquas a -60°. Pontos de verificação obtidos por receptor GNSS geodésico serão utilizados para avaliar a acurácia posicional. Os limites das parcelas foram interpretados a partir das ortofotos e os vértices comparados entre si e com as medições de campo. O objetivo foi avaliar a acurácia geométrica dos produtos fotogramétricos e identificar sob quais condições eles atendem às exigências legais da REURB. A proposta contribui para a definição de parâmetros técnicos confiáveis e viáveis ao uso de RPAs nos processos de regularização fundiária urbana no Brasil.

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1. Introduction

The unplanned occupation of urban areas represents one of the major challenges faced by Brazilian municipalities in the field of territorial management. This process, characterized by the irregular expansion of housing and subdivisions, compromises the population's quality of life, hinders effective urban planning, and generates land tenure conflicts that are difficult to resolve. The Federal Constitution of 1988, in Article 182, establishes that urban policy must regulate the full development of the city's social functions, assigning municipalities the responsibility of ensuring the well-being of their inhabitants.

Within this framework, in recent decades, specific legal instruments have been enacted to regulate land tenure, such as Law No. 10,931/2004, which addresses extrajudicial area rectification, and Law No. 13,105/2015, which introduced extrajudicial adverse possession. Among these, Law No. 13,465/2017 is particularly relevant, as it formalized the Urban Land Regularization (REURB), providing technical and legal mechanisms to legitimize occupations and strengthen land tenure security.

A fundamental requirement for the effective implementation of REURB is the availability of reliable cartographic bases capable of accurately representing urban parcel vertices. Conventional surveying techniques, based on GNSS receivers and total stations, have traditionally been employed for this purpose. However, large-scale application of these methods is often unfeasible due to their high operational costs and extended execution times.

In this context, the use of Unmanned Aircraft Systems (UAS) for photogrammetric mapping emerges as a technically viable and cost-efficient alternative. This technology enables the generation of high-resolution orthophotos within reduced timeframes and at lower costs. Nevertheless, the absence of specific regulatory standards for UAS-derived products raises concerns regarding their adequacy in applications that demand high positional accuracy, such as land regularization processes under REURB.

Accordingly, the primary objective of this study is to assess the geometric quality of photogrammetric products obtained from UAS and to propose technical guidelines that ensure their reliable and standardized adoption in urban land regularization.

2. STUDY AREA

The selected study area is located in the neighborhood of Ponta das Canas, in the municipality of Florianópolis, State of Santa Catarina, Brazil. The area covers approximately 15 hectares, comprising two entire blocks, three complete streets, and two segments of streets/avenues, as shown in Figure 1.

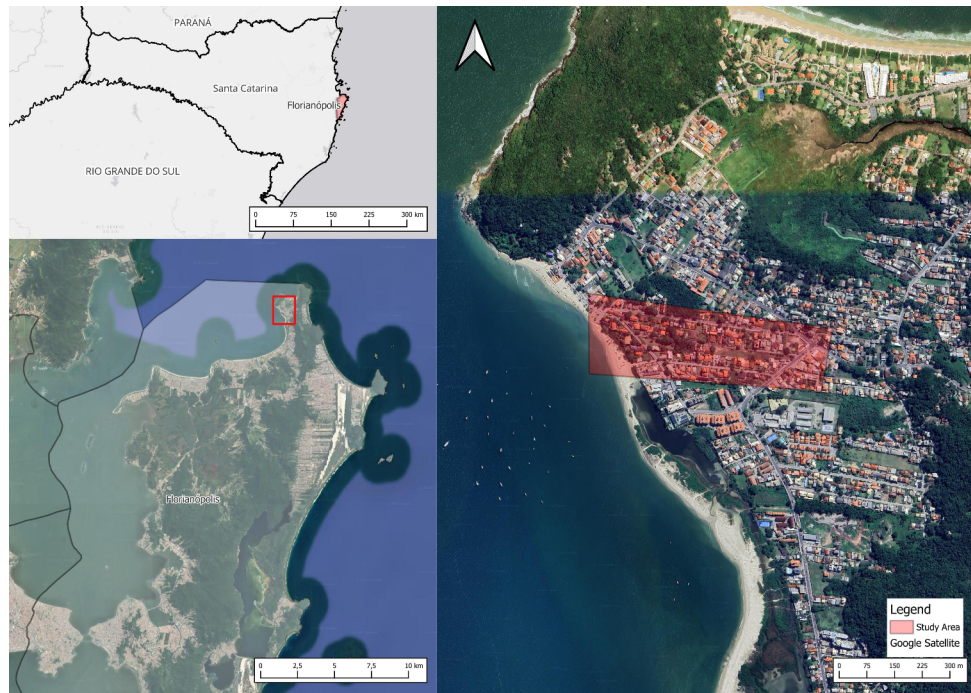


Figure 1. Study Area Location (source: the authors)

The area includes subdivisions with constructions along its boundaries, presenting parcel vertices that cannot be clearly identified through orthophotos. In addition, some vertices lack physical materialization, making their measurement feasible only through in-situ surveys or documentary sources.

3. METHODOLOGY

The methodology integrated aerial and ground surveys, with UAS flights conducted at different altitudes, generating orthophotos with ground sampling distances (GSD) of 5 cm, 2 cm (linear and oblique), and 1 cm, supported by RTK/PPK technology to ensure higher positional accuracy. Subsequently, a ground survey was carried out using a Total Station and a GNSS receiver. In this stage, property vertices that could be measured without entering the parcels were surveyed, along with control points for the flights. The images were processed in Agisoft Metashape 2.1, and the terrestrial survey data were adjusted in GeoOffice and Magnet Tools, followed by the vectorization of both datasets in QGIS. Accuracy assessment was performed in GeoPEC by applying the Student's t-test and the Chi-square test, in which the vertex coordinate values obtained from the four UAS surveys were compared with those from the ground survey.

3.1 UAS Surveying:

The Mavic 3 Enterprise (M3E) UAS was employed, with four flight plans designed using the DJI Fly application, an Android-based software integrated into the aircraft's remote controller. The controller is equipped with a GNSS positioning system with RTK correction,

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3-5 November 2025, Florianópolis, Santa Catarina, Brazil

implemented via NTRIP. The M3E features an RGB sensor with the following specifications: 4/3 CMOS, 20 MP, mechanical shutter.

All flights were conducted with a side overlap of 75% and a forward overlap of 80%. Except for the oblique flight, which was performed at tilt angles of 30°, 0°, and -30°, all others were carried out in nadir (perpendicular, 0°) orientation. Another distinction of the oblique flight is that it was executed using a cross-flight plan, whereas the remaining flights followed a linear plan, as shown in Figures 2, 3, 4, and 5.

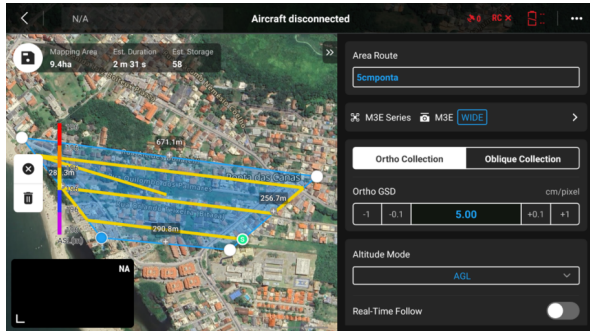


Figure 2. Flight plan with 5 cm GSD



Figure 3. Flight plan with 2 cm GSD

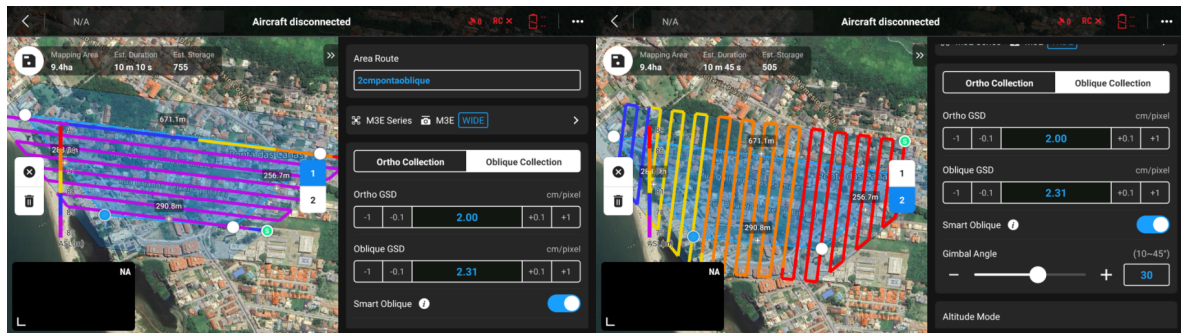


Figure 4. Oblique flight plan with 2 cm GSD

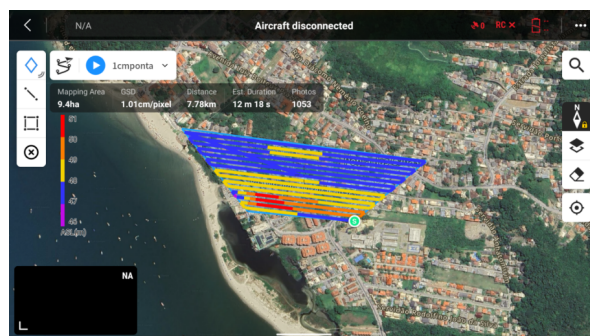


Figure 5. Flight plan with 1 cm GSD (source: the authors)

The image processing was carried out using Agisoft Metashape 2.1, in which the four flights were processed with the objective of generating a true orthophoto of the study area. The software provides several processing parameters, and the highest available processing mode was adopted to ensure product quality. To generate the orthophotos, the following steps were

followed: (1) photo alignment; (2) point cloud generation; (3) creation of the 3D model using depth maps; and subsequently, the generation of the true orthophoto from the 3D model.

A slight difference was observed between the planned Ground Sample Distance (GSD) and the values actually obtained. Table 1 presents the planned and achieved GSD values, as well as the number of captured images, flight duration, and processing time for each mission. Figures 6, 7, 8, and 9 provide a comparison of the products generated, displayed at a 1:20 scale, with each pixel analyzed for visual comparison.

Table 1. Flight Parameters (source: the authors)

Flight	Expected GSD	Achieved GSD	Type	Flight Altitude	Number of Photos	Flight Time	Processing Time
1	5 cm/pixel	5.62 cm/pixel	Linear	200 m	60	2min 31s	20min
2	2 cm/pixel	2.23 cm/pixel	Linear	83.1 m	288	4min 59s	1h 43min
3	2 cm/pixel	2.41 cm/pixel	Oblique	85 m	1,112	20min 55s	16h 53min
4	1 cm/pixel	1.16 cm/pixel	Linear	44.5 m	1,06	12min 18s	13h 11min



Figura 6. Achived GSD 5.62cm/pixel

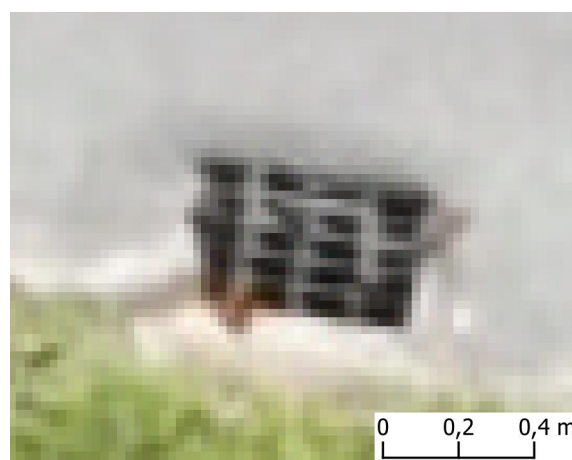


Figura 7. Achived GSD 2.23cm/pixel (linear)

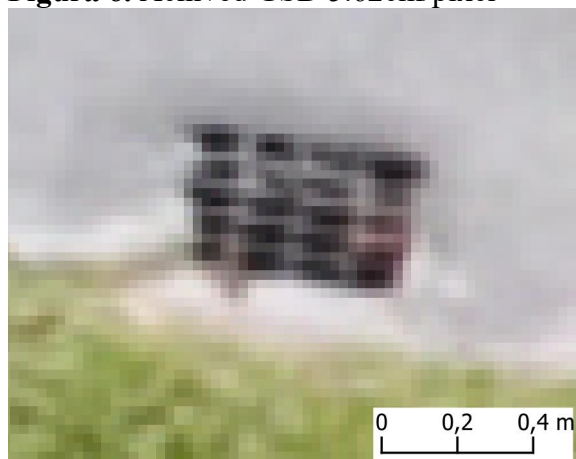


Figura 8. Achived GSD 2.41cm/pixel (Oblique)



Figura 9. Achived GSD 1.16cm/pixel

3.2 Topographic Survey

The topographic survey was carried out in accordance with NBR 13.133/2021 (ABNT) using Topcon HYPER VR GNSS receivers. The method applied was RTK-Radio, and the Base Point was also surveyed using the static method. Data processing was performed in Magnet Tools software. A total of 27 points were measured using this method, which were employed as check points to evaluate the positional accuracy of the orthophotos in relation to the traditional method and the requirements established by cadastral survey standards. Notable features such as manhole covers, storm drain corners, and street marking intersections were surveyed, as shown in Figure 10.

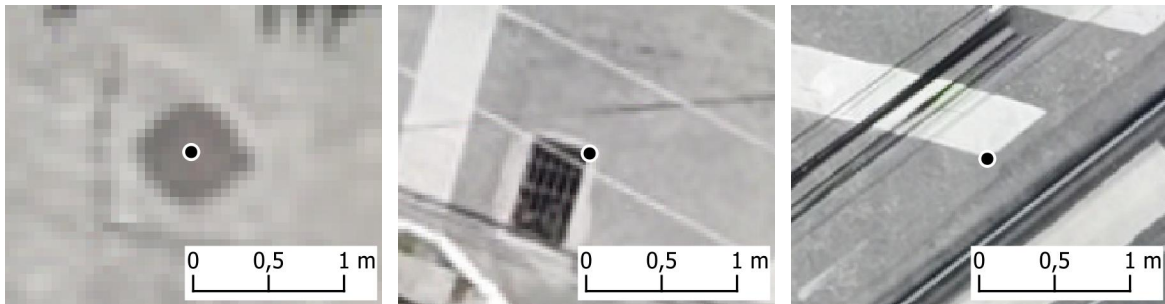


Figure 10. Manhole cover (5 cm/pixel), storm drain (2 cm/pixel), and pedestrian crosswalk (1 cm/pixel) (source: authors).

3.3 Vectorization and Extraction of Vertex Coordinates

The vectorization of the four orthophotos was carried out using QGIS software. The process began with the delineation of parcel boundary lines, assessing in each case the possibility of identifying the two vertices associated with each alignment. This assessment considered the presence of obstacles, such as tree cover, as well as the existence of materialized or visible features in the field. The choice to initially vectorize lines rather than points is also justified by the possibility of extending segments in situations such as property boundaries defined by walls, allowing the determination of vertices from the intersection of these alignments. This information is essential for the subsequent comparison of accuracies on an individualized basis (Figure 11).

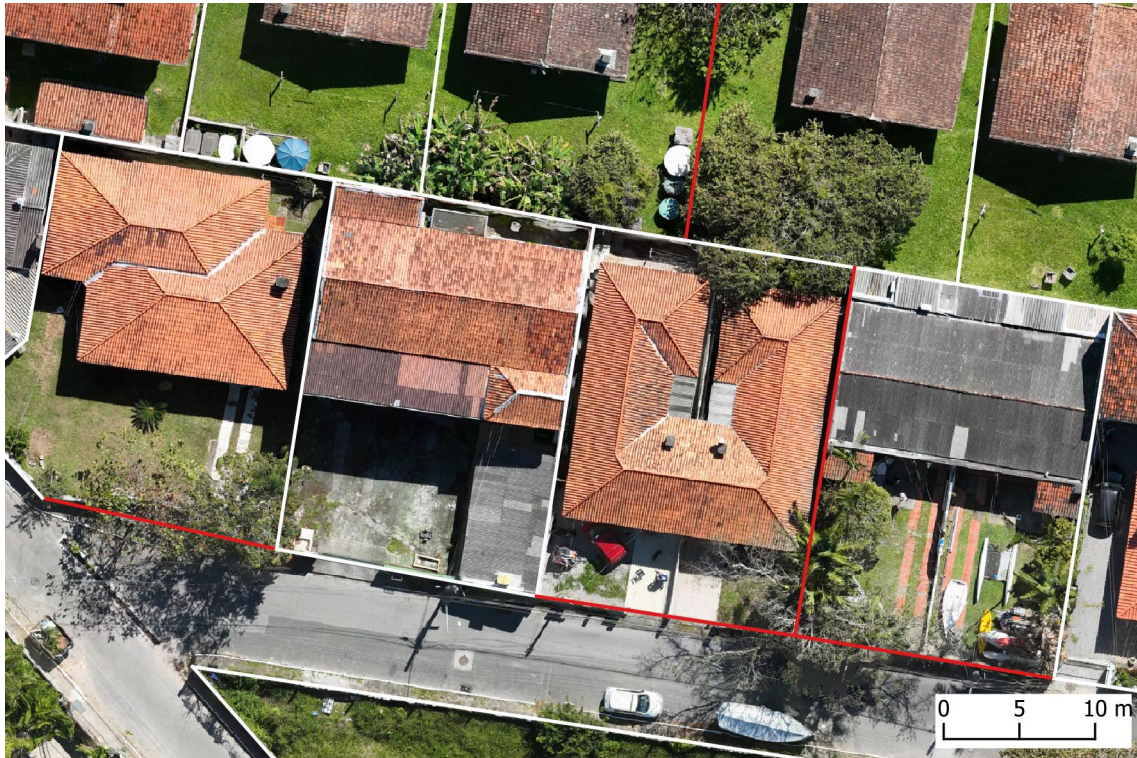


Figure 11. Vectorization of parcel boundary lines.

In the following stage, points were placed at all vertices based on the previously vectorized lines. These points were classified according to their method of acquisition: by line extension, by direct identification of materialized features (such as roofs or walls), arbitrarily when associated with less clearly defined materializations, and also at the intersections of extended lines (Figures 13 and 14). In addition, check points were positioned on the orthophotos according to the points surveyed in the field. In total, 202 vertex points and 27 check points were positioned. After the positioning of the points, their coordinates were extracted in QGIS using the Field Calculator tool and the \$X and \$Y functions (Figure 12). The E and N coordinates were obtained in the UTM Zone 22S projection, with the SIRGAS 2000 horizontal datum, which is the official reference adopted in Brazil. The use of the UTM projection allowed for the planimetric calculation of the differences between the coordinates obtained from the different surveys.

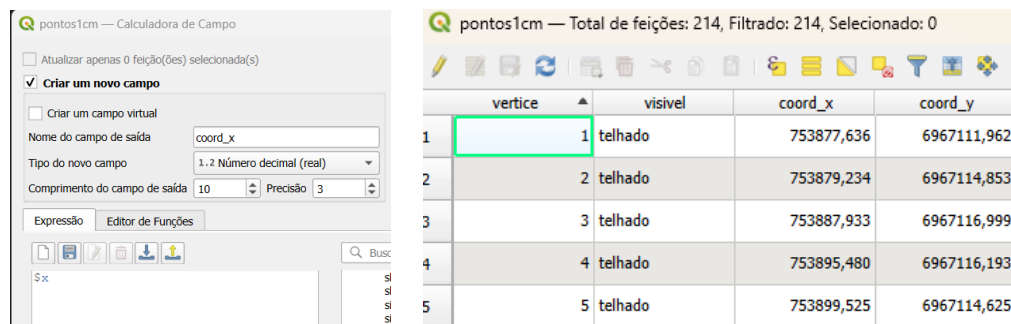


Figure 12. Field Calculator in QGIS and attribute table.



Figure 13. Vectorization of parcel vertices.



Figure 14. GCP and vertex points in the study area.

4. DISCREPANCY CALCULATIONS

The calculations were performed using GeoPEC 3.6 software, which employs algorithms following the procedures described in the standards and the methodology proposed by Santos et al. (2016). The software is free and available at <http://www.geopec.com>. Initially, discrepancies were calculated between the check points obtained from the topographic survey and those from the UAS survey, for both the x (Δx) and y (Δy) components. Subsequently, the mean (1) and standard deviation (2) of each component, as well as the horizontal (Hz) values, were computed as shown in Table 2.

$$\bar{\Delta x}, \bar{\Delta y} = \frac{1}{n} \sum_{i=1}^n \Delta x_i, \frac{1}{n} \sum_{i=1}^n \Delta y_i \quad (1)$$

$$s_{\Delta x}, s_{\Delta y} = \sqrt{\frac{\sum_{i=1}^n (\Delta x_i - \bar{\Delta x})^2}{n-1}}, \sqrt{\frac{\sum_{i=1}^n (\Delta y_i - \bar{\Delta y})^2}{n-1}} \quad (2)$$

Table 2. Differences in the x, y, and Hz components between check points.

	5cm/pixel			2cm/pixel (Linear)			2cm/pixel (oblique)			1cm/pixel		
	x (m)	y (m)	hz (m)	x (m)	y (m)	hz (m)	x (m)	y (m)	hz (m)	x (m)	y (m)	hz (m)
Mean	-0.065	-0.033	0.097	0.004	-0.038	0.058	0.051	0.022	0.032	0.060	0.022	0.031
Standard Deviation	0.046	0.066	0.47	0.041	0.040	0.035	0.020	0.026	0.023	0.018	0.021	0.017

4.1 Trend Detection

Trend verification was carried out based on the Student's t distribution. The hypotheses formulated for the test are:

$H_0: \Delta X' = 0$ (the orthoimage is free of trends)

$H_1: \Delta X' \neq 0$ (the orthoimage presents a trend)

Under the null hypothesis (H_0), the orthoimage is assumed to have no trend, meaning that its discrepancies have a zero mean at a given confidence level. The Student's t statistic is computed according to Equation (3):

$$t_x = (\Delta X' / s\Delta X) * \sqrt{n} \quad (3)$$

The calculated t_x value must be compared with the tabulated t value, which depends on the degrees of freedom (n-1) and the significance level ($\alpha/2$). The acceptance region for the null hypothesis is defined by Equation (4):

$$|t_x| < t(n-1, \alpha/2) \quad (4)$$

Therefore, for the null hypothesis (H_0) to be accepted, the calculated t_x value must be lower than the tabulated t value; otherwise, the hypothesis is rejected.

Table 3. Trend analysis of the 4 orthophotos.

	5cm/pixel			2cm/pixel (Linear)		2cm/pixel (oblique)		1cm/pixel	
	t tab	t calc	Trend	t calc	Trend	t calc	Trend	t calc	Trend
di(N)	1,7056	-2,0849	Presents	0,5576	free	1,3317	free	1,6307	free
di(Y)	1,7056	-2,6988	Presents	-4,9331	Presents	-4,3967	Presents	-5,317	Presents

4.2 Accuracy Analysis

The accuracy analysis was carried out by comparing the variances associated with the datasets and the tabulated Standard Error (SE) for the corresponding class. The SE is defined for a coordinate pair and was therefore compared with the sample standard deviation. In addition, the percentage of points with discrepancies lower than the SE was calculated, considering a 10% significance level.

To automate the calculations, the GeoPEC software was employed, adopting the values defined by EDGV according to the map scale and class. For the study area, the scale was estimated at approximately 1:470, which, according to the EDGV table, corresponds to a standard error of 0.008 m. This value is accepted by NBR 14047:2022 as the tolerance for urban cadastral surveys.

Table 4 presents the results of the accuracy assessment of the orthophotos with respect to the ground control points (GCP), showing the standard deviation values and the percentage of points outside the accuracy tolerance. Points identified as outliers were excluded from the sample.

Table 4. Accuracy Comparison

	s	% $\Delta hZ < SE$	Outlier	Result
5cm/pixel	0,047	84,615	1	Reproved
2cm/pixel Linear	0,035	100	0	Aproved
2cm/pixel Oblique	0,023	100	0	Aproved
1cm/pixel	0,017	100	0	Aproved

The standard error and accuracy between the images were also calculated. In this case, the orthophoto with a GSD of 1 cm was adopted as the reference, in relation to the other three orthophotos, and the vertices extracted from each were compared. From this comparison, the mean, standard deviation, trend, and accuracy analysis among the images were obtained, as presented in Tables 5 and 6.

Table 5. Trend analysis comparison

	s	% $\Delta hZ < SE$	Outlier	Result
5cm/pixel	0,091	43,243	12	Reproved
2cm/pixel Linear	0,081	72,105	11	Reproved
2cm/pixel Oblique	0,074	75,63	10	Reproved

Table 6. Accuracy comparison

	5cm/pixel			2cm/pixel (Linear)		2cm/pixel (oblique)	
	t tab	t calc	Trend	t calc	Trend	t calc	Trend
di(N)	1,6532	-11,2062	Presents	1,7826	Presents	1,7826	Presents
di(Y)	1,6532	2,9137	Presents	0,7604	free	0,7604	free

5. ANALYSIS OF THE RESULTS OBTAINED

When analyzing the results, a clear improvement in positional accuracy was observed as the GSD decreased, due to the better identification of notable features and the improvement in the positioning and adjustment of the orthophotos.

It was also verified that all orthophotos exhibited a consistent trend along the Y-axis, which may be attributed to factors such as displacement in the reference point of the GNSS-RTK base or instability in the NTRIP base used during the flights. The distance of more than 20 km from the NTRIP base likely contributed to the observed errors, highlighting the need for additional comparative tests with surveys performed using RTK-Radio and a local known base.

The comparison of parcel vertices in the orthophotos, although not meeting the required accuracy in all cases, demonstrates the need for complementary analyses through complete ground surveys of the study area. This would enable a direct comparison between vertices extracted from the orthophotos and those obtained in the field. Among the identified outliers, more than 90% were related to points determined by the extension and intersection of line segments, with only one wall vertex appearing as discrepant across all three analyses.

Thus, although further studies are necessary — including comparisons restricted to vertices associated with clearly identifiable features in the imagery, validation against conventional topographic surveys, application of alternative real-time positioning methods, and testing with UAVs equipped with different sensors and positioning technologies — the results allow for preliminary conclusions.

It was found that, by applying a tolerance of three times the established standard error (8 mm), reaching 24 mm, orthophotos with 1 cm/pixel and 2 cm/pixel GSD met the accuracy requirements for all measured vertices. Therefore, one of the primary criteria in flight planning should be the adoption of a GSD less than or equal to 2 cm/pixel, without the need for oblique flights, as these did not produce significant improvements in mean values or standard deviations.

Similarly, the use of 1 cm/pixel GSD proved unnecessary, as flight time was more than three times longer and processing time more than ten times greater, significantly increasing computational costs and requiring higher-performance equipment.

In conclusion, despite the need for additional analyses involving different technologies, it can be stated that the use of the DJI M3M drone with RTK/NTRIP positioning satisfactorily meets the accuracy standards established by NBR 14047 — 8 cm for cartographic elaboration and up to 24 cm for comparative analyses with other methods — when flight planning is conducted with a GSD of 2 cm/pixel.

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