COMPARATIVE ANALYSIS OF LOW-COST CONSUMER-GRADE AND COMMERCIAL-GRADE DRONES FOR LAND SURVEYING APPLICATIONS

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ABSTRACT:

This study investigates the feasibility of using low-cost consumer drones, specifically the DJI Mini 2, for land surveys compared to commercial-grade drones like the DJI Phantom 4 Pro V2. The research, conducted within the University of the Philippines - Diliman campus, evaluates the horizontal accuracy of resulting ortho-images and explores the advantages and disadvantages of each platform. Initiated by the recognition of aerial drones' transformative impact on land surveying, particularly acknowledged by the Land Management Bureau in the Philippines, the study addresses concerns about the use of consumer-grade drones for surveying. While some advocate for commercial-grade drones, citing concerns about accuracy, a prior study in India demonstrated the suitability of consumer-grade drones for geomatics applications. The methodology involves creating a flight plan with specified parameters for both drones, establishing Ground Control Points (GCPs), and conducting two flights. The results, processed using UAS Mapping Workflow, indicate comparable errors between the consumer-grade DJI Mini 2 and commercial-grade DJI Phantom 4 Pro V2. Despite slight differences, both drones meet the accuracy standards for land surveys. The study contributes to the discourse on affordable means of secure land tenure, envisioning consumer-grade drones as viable alternatives for cost-effective land surveys. The DJI Mini 2, at a fraction of the cost, demonstrates the capability to achieve accuracy levels comparable to its commercial counterpart. While acknowledging the need for further testing and optimization, the findings suggest the potential of consumer-grade drones in advancing sustainable urban development and poverty reduction through accessible land survey methods.

1. INTRODUCTION

1.1 Background

Unmanned aerial systems (UAS), commonly known as aerial drones, have completely changed the land surveying industry by providing a reasonably accurate and affordable way of data collecting (Fitzpatrick, 2016). The Foundation for Economic Freedom, Inc. (FEF) initiative Technology for Property Rights, which began back in 2016, also demonstrated this. In line with this, the Land Management Bureau Memorandum Circular 2017-003 or LMC 2017-003 (2017a) institutionalized the use of UAS in the Philippines, recognizing their capabilities and applicability, particularly in property surveying.

According to Land Management Bureau Technical Bulletin No. 2 Series of 2017 (2017b), using UAS has been proven to meet accuracy standards for land surveys. This is achieved by achieving a root mean square error (RMSE) of 4.1 cm, which aligns with the allowable position error of ±10 cm for relocation and verification surveys as specified in Section 30 of the Department of Environment and Natural Resources Administrative Order No. 2007-29 or DAO 2007-29 (2007).

The study by Madawalagama et al. (2016) contradicts the acceptance of commercial-grade drones by various organizations (Atom, 2023; Propeller, 2023). The accuracy of consumer-grade drones in a variety of geomatics applications is demonstrated in their research, which raises the possibility of a shift toward these less expensive options in surveys and mapping and increases access to low-cost geospatial data collecting techniques.

1.2 Objectives

Building on prior research, this study seeks to compare low-cost consumer drones and commercial-grade drones for land surveys. The primary focus is on assessing their ability to meet local accuracy standards. The evaluation will center on the horizontal accuracy of generated ortho-images, accompanied by a comprehensive examination of the advantages and disadvantages inherent in each platform's surveying capabilities.

1.3 Rationale

Drawing from FEF's 2020 report, which highlights approximately 6 to 8 million untitled land parcels in the country, the imperative of addressing land tenure security emerges as a critical development challenge. While the adoption of UAS has already enhanced the efficiency of land surveys, the potential integration of low-cost drones into the process offers a promising avenue for further improvements, provided they can meet established accuracy standards.

This initiative not only aligns with the national goal of accelerating survey plan production but also contributes to the broader objective of making cities and human settlements more sustainable. By exploring the use of cost-effective consumer-grade drones, the study aims to facilitate secure land tenure, empowering local surveyors and geodetic engineers. This endeavor, if successful, holds the potential to significantly contribute to the Sustainable Development Goals outlined by the United Nations in 2015, particularly in advancing "Goal 1: No Poverty," where land tenure security serves as a vital indicator.

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1.4 Study Site

The research area was conducted on a piece of land within the University of the Philippines - Diliman campus, spanning approximately 4.5 hectares. It includes various features like roads, trees, grass, and other infrastructures. This site has been chosen as it is an open field area, making it easy for the takeoff and landing of the UAVs, and for the researchers to distribute and establish Ground Control Points (GCP).

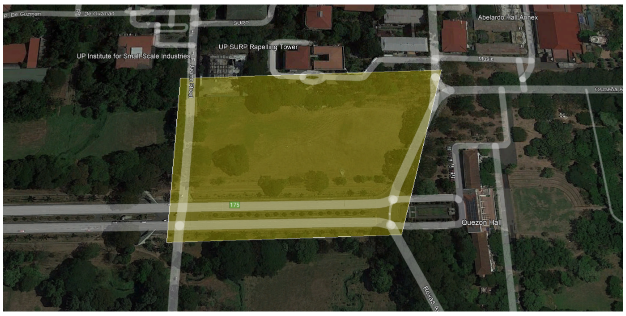

Figure 1. Study Site in UP Diliman Campus

2. REVIEW OF RELATED LITERATURE

For the comparison of this study, the DJI Mini 2 was used for the consumer-grade drone category, while the DJI Phantom 4 Pro V2 was used for the consumer-grade drone category. Shown below is a comparison of the technical specifications of each platform and their respective built-in sensors.

Description	DJI Mini 2	DJI Phantom 4 Pro V2
Camera	FC7303 (4.49mm, 12MP)	FC6310S (8.8mm, 20MP)
Max Flight Time	31 minutes	31 minutes
Weight	< 249 g	1.36 kg
Dimensions	Folded: 138×81×58 mm Unfolded: 159×203×56 mm	15.7"L x 9.9"W x 6.75"H
Price	~ 35,000 PHP (600 USD)	~ 200,000 PHP (3300 USD)

Table 1. Comparison of DJI Mini 2 and DJI Phantom 4 Pro V2

Table 1 highlights several key distinctions between the DJI Mini 2 and the DJI Phantom 4 Pro V2. Notably, the DJI Mini 2 boasts a smaller focal length compared to the DJI Phantom 4 Pro V2. A striking difference lies in the cost, with the DJI Phantom 4 Pro V2 priced at five times more than the DJI Mini 2.

However, as expressed by Ciobanu (2022), although the DJI Mini 2 has the capabilities to be used for mapping, its outputs may fall short when compared to commercial-grade UAVs such as the Mavic 2 Pro or Phantom Series. However, this was not supported by accuracy assessment metrics, which will try to be addressed in this study.

2.1 DJI Mini 2 (Consumer Drone)

Released in November 2020, DJI Mini 2 is a low-cost, lightweight drone with a max flight distance of 15.7 km and a max flight time of 31 minutes. Weighing less than 249 grams and carrying a 12MP camera, the DJI Mini 2 supports GPS+GLONASS+GALILEO and costs less than 35,000 Philippine pesos (600 USD).

The DJI Mini 2 has drawn notice for its versatility beyond its primary purpose of taking casual photos and movies. It is noteworthy that it has found use in mapping applications, expanding its usefulness to more complex applications. A flight planning tool that offers a seamless connection with the DJI Mini 2 and enables users to develop specialized and effective flight plans is Drone Harmony (2023), which was used for this study.

Figure 2. Image of DJI Mini 2 with its accessories (DJI, 2022b)

2.2 DJI Phantom 4 Pro V2 (Commercial Drone)

The DJI Phantom 4 Pro V2, introduced in May 2018, stands as a robust unmanned aerial vehicle (UAV) tailored for mapping and orthomosaic production. With a maximum flight distance of 7.0 km and a flight time of approximately 30 minutes, this UAV weighs 1375 grams and features a 20MP camera. The incorporation of GPS/GLONASS enhances its navigational capabilities. Valued at around 200,000 Philippine pesos (equivalent to 3300 USD), the Phantom 4 Pro V2 is positioned as a commercial-grade solution for precision mapping.

Given its mapping focus, the Phantom 4 Pro V2 aligns seamlessly with various flight planning applications, offering users the ability to generate efficient flight plans. Notably, Drone Harmony (2023) is one such application that supports this UAV, providing users with a user-friendly interface for creating tailored flight plans. To maintain consistency in the comparison between the DJI Mini 2 and the DJI Phantom 4 Pro V2, the study opted for Drone Harmony for flight planning on both platforms.

Figure 3. Image of DJI Phantom 4 Pro V2 with its accessories (DJI, 2022a)

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2.3 GNSS Survey for Ground Control Point Establishment

The GNSS-derived coordinates of the GCPs played a pivotal role in the UAS Mapping Workflow adopted for this study, following the methodology proposed by Volkmann and Barnes (2014). Integration of these control points ensured the alignment of the drone-acquired data with real-world coordinates, contributing to the precision of the final orthomosaics.

By employing GNSS observations in the GCP survey, this methodology establishes a robust foundation for accurate spatial referencing and assessment of the resulting orthomosaics, contributing to the reliability of the study's findings and the overall quality of the survey outcomes.

3. METHODOLOGY

This study adopts the UAS Mapping Workflow of Volkmann and Barnes (2014). Figure 2 shows a quick overview of the stages undertaken in the conduct of the survey.

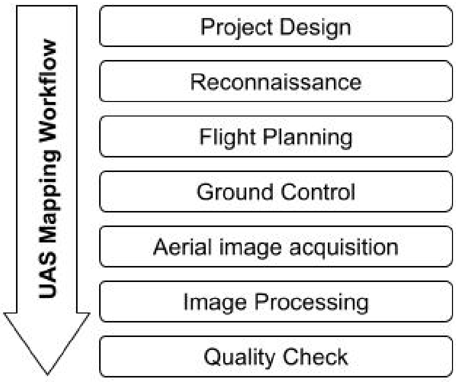

Figure 4. UAS Mapping Workflow (Volkmann & Barnes, 2014)

3.1 Project Design, Reconnaissance, and Flight Planning

A flight plan was created in Drone Harmony with an 80% side overlap and 80% front overlap, with a flying speed of 8.0 m/s, and about 130-140 images. Table 2 shows a comparison between the specifications of the flight plans produced for the DJI Mini 2 and DJI Phantom 4 Pro V2.

Description	DJI Mini 2	DJI Phantom 4 Pro V2
Flying Time	9 mins (80 m)	8 mins (80 m)
Number of Photos	128 (80 m)	138 (80 m)

Table 2. Flight Parameters of DJI Mini 2 and DJI Phantom 4 Pro V2

The flying times and number of photos are almost similar and are within their maximum flying time thresholds. Table 3 compares the resultant products of DJI Mini 2 and DJI Phantom 4 Pro V2 for the 80-meter flying height after post-processing.

3.2 Ground Control

To ensure the accurate production of orthomosaics and to facilitate accuracy assessment, a meticulous Ground Control Point (GCP) survey was conducted employing Global Navigation Satellite System (GNSS) observations. 20.6 cm x 26.8 cm ground control markers were created and used for this study. While the specification for the markers was arbitrary, the dimensions were still sufficient to be visible from the images obtained using both drones. Figure 5 shows a sample of the devised marker.

Figure 5. Sample ground control marker used as GCP.

3.2.1 Establishment of Ground Control Points (GCPs): Seventeen artificial Ground Control Points were strategically distributed throughout the study site within the University of the Philippines - Diliman campus, covering approximately 4.5 hectares. The selection of GCP locations took into account the diverse features of the terrain, including roads, trees, grass, and other infrastructures.

3.2.2 GNSS Survey: The coordinates of these GCPs were determined with precision using GNSS technology. The survey involved the utilization of GNSS receivers in conjunction with the base station MMA-5 located in the College of Engineering, UP Diliman. This ensured a high level of accuracy in establishing the spatial coordinates of the GCPs.

Figure 6. Setup of one of the GNSS Survey done to measure the coordinates of the GCP markers

3.2.3 Distribution and Verification: The GNSS-derived coordinates of the GCPs were carefully distributed and verified to guarantee their accuracy and reliability. The rigorous distribution aimed to cover the entire study area, allowing for a comprehensive assessment of the accuracy of the resulting orthomosaics.

3.2.4 Control and Check Points: In the subsequent data processing phase, eleven GCPs were employed as control points, forming a robust foundation for the adjustment and georeferencing of the orthophotos. Additionally, six GCPs were reserved as check-points for subsequent comparison, aiding in the validation of the accuracy of the generated orthomosaics.

3.3 Aerial Image Acquisition

A total of two (2) flights were conducted: one (1) flight for each platform DJI Mini 2 and DJI Phantom 4 Pro V2 at eighty (80) meters flying height. All other flight plan specifications were kept the same, varying the platform and sensor. GCPs were processed in Trimble Business Center software and set in the WGS 84 UTM Zone 51N coordinate system. All other photogrammetric processing was performed in Agisoft MetaShape.

3.4 Image Processing and Quality Control

This part pertains to the photogrammetric processing of the images to produce a map of the study area. The Agisoft Metashape for the processing following the workflow is shown in Figure 7. The images for each drone were stored in separate chunks. For the first part, the alignment of photos was implemented at the highest accuracy with a key point limit and tie point limit of 40,000 and 4,000 respectively. Other parameters were set to default settings.

After the alignment process, the processing was further optimized by the careful selection of GCPs with precise or accurate alignment with the aligned images. Note that this part heavily relies on the subjective capability of the researcher in selecting good GCPs. This was then followed by the georeferencing of each of the drone images.

Once all the images were already carefully georeferenced, camera optimization was implemented followed by the mesh generation which was used to generate the DEM and the Orthomosaic of the study area. An important parameter to note during the camera optimization process is the adaptive camera model fitting which was toggled for this study.

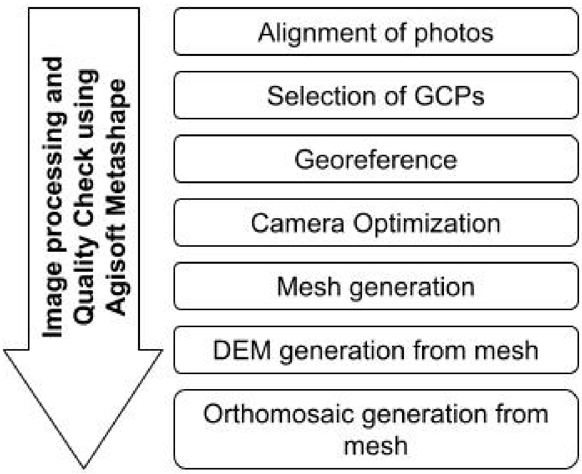

Figure 7. Photogrammetry workflow adopted in this study which included the image processing process and quality check.

It must be noted that in the Camera Optimization, the Adaptive camera model fitting was selected to produce good camera calibration parameters, as suggested in the User Manual of Agisoft Metashape (2023).

4. RESULTS AND DISCUSSION

4.1 Comparison of Raw Images taken using DJI Mini 2 and DJI Phantom 4 Pro V2

The following images show snapshots of the same ground control markers from the images captured by the two drones. The left image was captured by the Mini 2 while the right one was captured using the Phantom 4 pro V2. From these two images, there is a significant difference between the camera sensors of the two drones. While the 20 mp camera of Phantom 4 Pro V2 captured a much finer image however, details were washed out due to the higher exposure which can be attributed to the variable aperture of the camera sensor allowing it to automatically adjust to the general exposure of the environment at the time of acquisition. This implies that the camera sensor did not have consistent parameters throughout the total flight. The image of Mini 2 on the other hand showed clearer detail despite the lower pixel specification and fixed aperture of the sensor.

Figure 8. Snapshots of the GCPs from the images captured by DJI Mini 2 (left) and DJI Phantom 4 pro V2 (right) at 80-meter flying height.

Based on these snapshots, while the GCPs were visible from the images, there is a clear indication that the dimensions were lacking. From there, it can therefore be recommended that proper design of ground control markers must be implemented in order to ensure the accuracy of the photogrammetric workflow most especially in the georeferencing process. Nevertheless, the researchers were able to sufficiently georeference the drone images in the software, taking the center of the hazy markers, as suggested in section A.4.7.iv of the Land Management Bureau Technical Bulletin No. 2 Series of 2017 (2017b).

4.2 Data Processing Outputs of Surveys Conducted using DJI Mini 2 and DJI Phantom 4 Pro V2

The following maps show the generated orthomosaic using the drone photos captured using the two drones. The main difference which can be observed from the two maps is the quality. The orthomosaic of Phantom 4 was relatively brighter compared to that of the Mini 2 which showed a higher contrast. Moreover, despite the Phantom 4 producing a finer orthomosaic due to it having a larger pixel quantity, the Mini 2's orthomosaic looked sharper and more detailed - which could be preferred in conducting land surveys for better identification of features on the orthomosaics.

In terms of model quality, the stitching of the drone photos was seamless in both orthomosaics. There was no significant distortion observed within the boundary of the study area. Overall, there is no significant difference between the two orthomosaics which suggests that the DJI Mini 2, despite its inferior camera sensor, can be used to produce high-quality photogrammetry models, in this case, the orthomosaic, comparable to that of the Phantom 4.

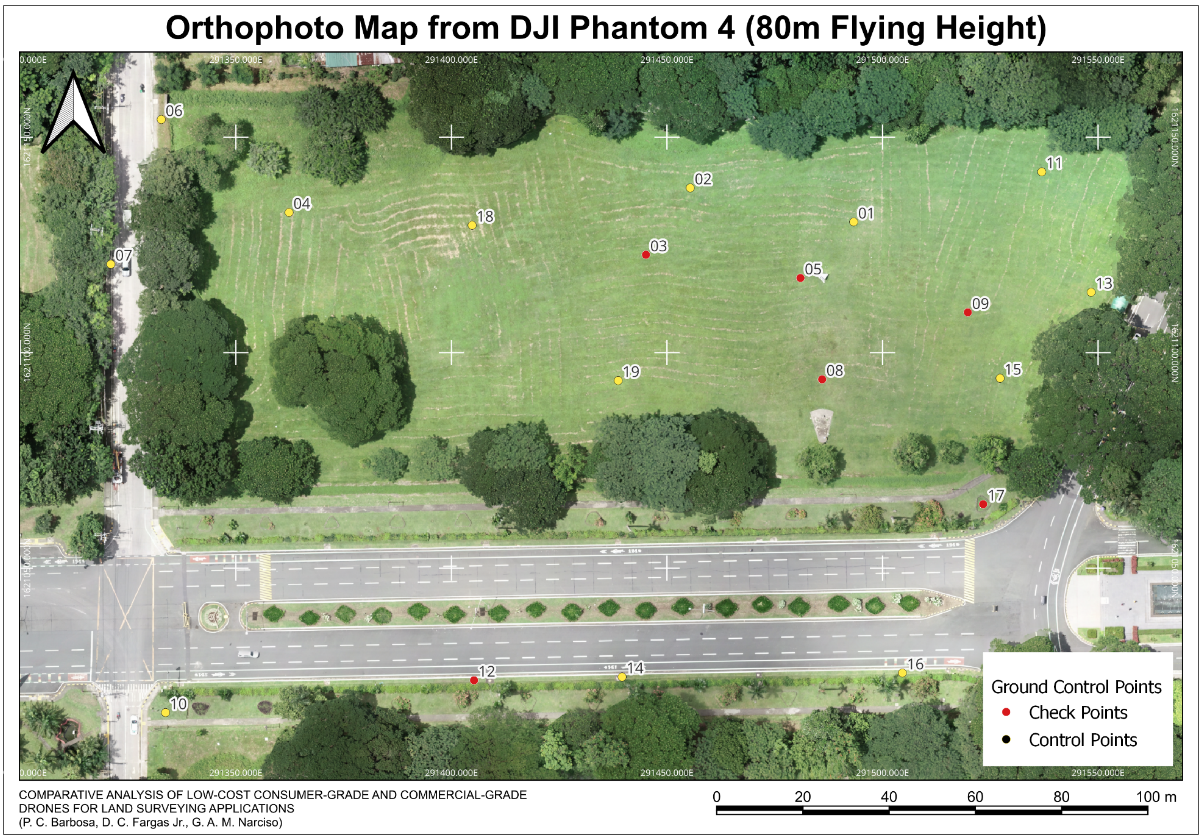

Figure 9. Orthomosaic generated using images captured from DJI Phantom 4 at 80-meter flying height

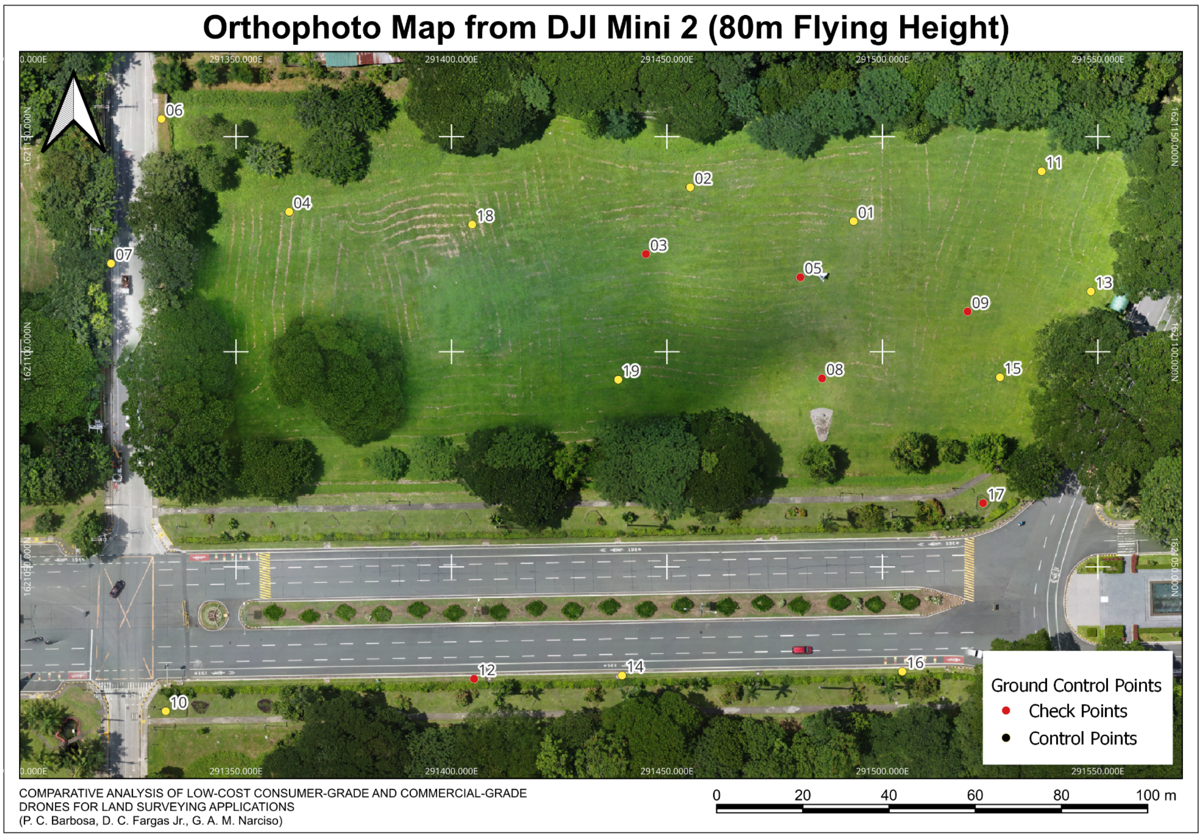

Figure 10. Orthomosaic generated using images captured from DJI Mini 2 at 80-meter flying height.

4.3 Comparison of Processing Output Parameters

Description	DJI Mini 2	DJI Phantom 4 Pro V2
Ground Resolution	2.58 cm/pix	2.37 cm/pix
Reprojection error	0.682 pix	1.05 pix
Mean key point size	7.67003 pix	5.90696 pix
X Error RMSE (Control)	0.0448907 cm	0.0332331 cm
Y Error RMSE (Control)	0.0541892 cm	0.0558707 cm
Z Error RMSE (Control)	0.0236471 cm	0.00455269 cm
XY Error RMSE (Control)	0.0703679 cm	0.0650075 cm
XYZ Error RMSE (Control)	0.074235 cm	0.0651668 cm
X Error RMSE (Check)	1.4017 cm	1.49675 cm
Y Error RMSE (Check)	2.10157 cm	1.913 cm
Z Error RMSE (Check)	20.5673 cm	3.64102 cm
XY Error RMSE (Check)	2.52613 cm	2.42896 cm
XYZ Error RMSE (Check)	20.7219 cm	4.37686 cm
Average tie point multiplicity	3.58704	5.62998 cm

Table 3. Comparison of Processing Output Parameters for DJI Mini 2 and DJI Phantom 4 Pro V2

As seen in Table 3, it appears that both the DJI Mini 2 and DJI Phantom 4 Pro V2 have virtually similar errors, except for the Z error, wherein the DJI Mini 2 had a significantly higher RMSE value. However, both platforms were able to produce an XY Error RMSE that is less than 4.1 cm - which is within the accuracy standard for land surveying.

This could be mainly attributed to the camera sensor specifications of the two drones. The 20 mp camera sensor and the variable aperture of the Phantom 4 Pro V2 enabled better tie point identification due to its better capability of capturing unique features at higher resolution as compared to the Mini 2's 12 mp camera sensor with fixed aperture.

With regards to the difference in the accuracy of the elevation or Z-values, it can be explained by the aperture difference since it does not only control the exposure of the image but it also improves the depth perception of the camera sensor which is key to the measurement of distances from the sensor's focal point to the surface feature.

Aside from the camera sensor, other specifications of the drones can also be a source of errors such as their GNSS sensor and the presence of a gyroscope. It can be observed that the DJI Mini 2 yielded a significantly high Z Error RMSE since it doesn't give a highly accurate position with its GNSS sensor and a gyroscope to compensate for tilt, unlike the DJI Phantom 4 Pro V2.

Another difference to take into account is the focal lengths. Phantom 4 pro V2 has a focal length of 8.8 mm while 4.49 mm for the Mini 2 which simply translates to the area coverage of the image that one sensor can capture. Since the Mini 2 has a shorter focal length, this makes it better at capturing a wider area in one image. This can be considered an advantage for Mini 2 allowing it to capture fewer photos than Phantom 4 pro V2 for the same project extent.

Concerning external considerations, processing parameters can also be factors in the accuracy of the generated model. Given the sensor differences between the two drones, customized processing parameters may be required for each drone in order to produce more accurate results (i.e., different methods or parameters may be required for processing images with and without gyroscope, good and bad geotagging, etc.).

5. CONCLUSION

5.1 Summary

In summary, for the fieldwork conducted for this study, it can be said that the DJI Mini 2 and the DJI Phantom 4 Pro V2 were able to produce orthophoto maps that have an XY RMSE that are within the prescribed accuracy for land surveys.

However, it should be noted that the DJI Mini 2 produced a significantly high Z error, while the Phantom 4 Pro V2 was able to yield low values. As a consequence, this could have implications when DJI Mini 2 is used to produce digital elevation maps.

With this, it is safe to assume that at one-fifth of the cost, the DJI Mini 2, a consumer-grade UAV, can produce products that are within the accuracy standards for land surveys, and that are close to the accuracy of the DJI Phantom 4 Pro V2, a commercial-grade UAV.

5.2 Recommendations

The following are some recommendations for future research endeavors that may contribute to a more comprehensive understanding of the capabilities and limitations of consumer-grade drones in land surveying applications.

5.2.1 Vary Flight Parameters: The study suggests that future research should explore the impact of varying flight parameters on the accuracy of land surveys conducted with consumer-grade drones. Variability in flight parameters could address potential sources of error and contribute to a more comprehensive understanding of the capabilities and limitations of consumer-grade drones in different settings.

5.2.2 Explore Sites with Different Characteristics: To enhance the generalizability of findings, extending the research to sites with diverse characteristics is recommended. Different terrains, vegetation, and environmental conditions can influence the performance of drones in data acquisition. Conducting surveys in varied settings, such as urban, rural, or areas with complex topography, will contribute to a more robust assessment of consumer-grade drones' applicability. This approach will provide a nuanced understanding of how these drones perform under real-world conditions and aid in refining guidelines for specific surveying contexts.

5.2.3 Diversify Drone Models: The study focused on the DJI Mini 2 as a representative consumer-grade drone and the DJI Phantom 4 Pro V2 as a commercial-grade counterpart. However, the rapidly evolving drone market offers a variety of models with different specifications. This diversification will help identify trends, patterns, or specific features that contribute to or hinder accuracy, enabling stakeholders to make informed decisions when selecting a drone for land surveying purposes.

5.2.4 Longitudinal Studies: To capture the evolving landscape of drone technology, it is recommended to conduct longitudinal studies that track the performance of consumer-grade and commercial-grade drones over time. This could involve assessing the impact of software updates, hardware improvements, and industry standards changes. Longitudinal studies would provide valuable information on the sustainability of consumer-grade drones in maintaining accuracy levels compared to their commercial-grade counterparts and contribute to ongoing advancements in drone-assisted land surveys.

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