Linear Measurement Accuracy of DJI Drone Platforms and Photogrammetry

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Abstract

Drones are quickly becoming the go-to means for the collection of on-demand aerial imagery across industries such as construction, surveying, insurance, and mining. Photogrammetry allows us to digitalize the physical world and use that data to solve some of today's toughest challenges. In the process, it eliminates the need to manually capture data in dangerous areas such as industrial jobsites, quarries, roofs, and other elevated structures.

Photogrammetry relies on cameras to measure real-world objects and turn 3D space into 2D maps. This requires photogrammetry software to identify the location, orientation, and movement of the camera to calculate the position of three-dimensional points. Without a physical relationship between the camera and the subject being mapped, it is difficult to quantify the accuracy of photogrammetric outputs. Therefore, to properly quantify error the outputs must be ground-truthed against known values.

Cameras are physical devices that introduce errors into the data capture process. A camera's 2D image isn't a true representation of the physical world. This is because camera bodies and lenses cannot be manufactured perfectly, which create errors—such as distorted lines in a photo—that photogrammetry software must compensate for. These errors, even when compensated for, can create inaccuracies in linear measurements made on a processed map.

In this study DroneDeploy has investigated ways to improve mapping accuracy and put together a set of best practices to be used when making linear measurements. To test the accuracy of the measurements made using maps generated from data captured with industry-standard DJI drone platforms, DroneDeploy established a ground control system on the roof of its office. Then, more than 80 flights were logged—each exploring different flight altitudes, cameras, and photo overlap settings. The images collected were then processed in the cloud using the DroneDeploy map engine.

The data sets were analyzed and used to calculate the average margin of error for measurements of known control lengths. Using the results, DroneDeploy determined that using a performance camera and flying at low altitude with high image overlap produced maps with the best linear measurement accuracy.

Introduction

Goals of This Study

When it comes to drone data, there is one metric that matters most: accuracy. Over the last few years, as drone technology has advanced, so too has the ability for drone maps to be highly accurate. But photogrammetric accuracy is poorly understood—particularly among those who are new to aerial mapping or just entering the commercial drone industry. To help shed light on this topic and provide businesses with access to reliable data, DroneDeploy conducted an experiment to assess the overall linear measurement accuracy of drone maps captured by standard DJI drone platforms and processed in the cloud using the DroneDeploy map engine.

The goal of this study was to provide quantitative data and guidelines for what users can expect from linear measurements on models created with cloud-based photogrammetry software. This study also included the relative accuracy of data collected and processed with and without the use of ground control points (GCPs). The results provide insight into the accuracy one can expect from each method and data to aid in deciding whether a DroneDeploy mapping mission requires the use of ground control points.

Exploring Best Practices for Photogrammetric Data Collection

This paper provides guidance on how to improve the quality of input data collected using DJI drone models and cameras when producing maps on the DroneDeploy platform. This study, compares image results from a wide range of hardware options to determine the optimum flight settings for producing maps that can deliver accurate 2D measurements. The results can serve as guidelines when selecting flight parameters for mapping missions including: altitude, sidelap, and frontlap.

Drone Models Used in This Study

The DJI drone models chosen for this exercise included the Mavic Pro, Phantom 3 Pro (P3P), Phantom 4 Pro (P4P), Inspire 1 (with DJI X3 Camera), Inspire 1 Pro (with DJI X5 Camera), and Inspire 2 (with DJI X4s Camera). The other DJI Phantom 3 models and the DJI Phantom 4 were excluded because these models share the same 12MP camera sensor included in the Phantom 3 Pro.

DroneDeploy chose to conduct this study with DJI drones because they are the number one camera and hardware platform used by professionals in the commercial drone industry. As these drones are the primary choice of DroneDeploy customers across industries including construction, agriculture, inspection, surveying, and mining, this dataset provides DroneDeploy's largest customer base insight into the accuracy that is capable with their hardware solution of choice.

Camera Sensors

There were a variety of sensors used to collect data in this study ranging from 12MP, 1/2.3" to 20MP, 1". This selection represents the full range of DJI cameras available on the market today and includes both mechanical and electronic camera shutters. The sensor specifications and characteristics can be found in Figure 1 and Table 1.

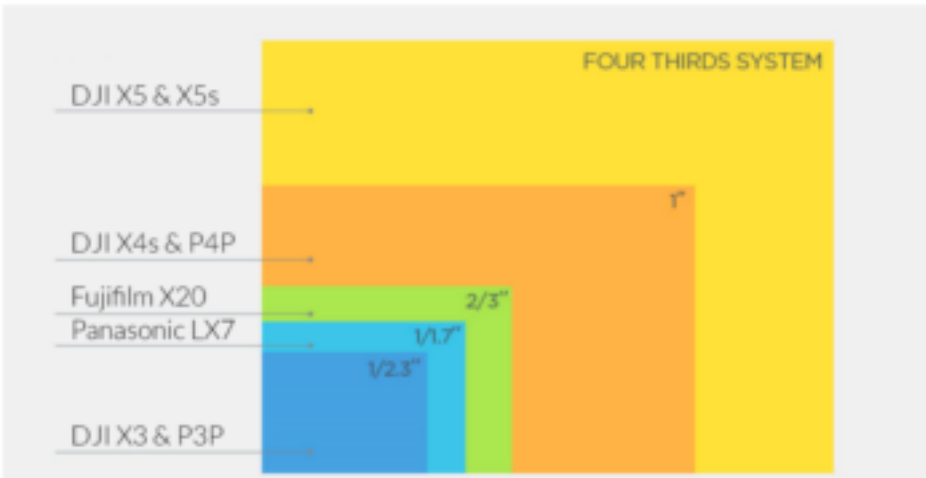

Figure 1. Camera Sensor Sizes

Drone	Megapixels	Sensor Size	Field of View	Shutter Type
P3P & I1 (X3)	12MP	1/2.3"	94°	Rolling
Mavic Pro	12MP	1/2.3"	78°	Rolling
P4P & I2 (X4s)	20MP	1"	84°	Mechanical
I1 Pro (X5)	16MP	4/3"	72°	Rolling

Table 1. Camera Sensor Specifications

Background

Standard Deviation of Linear Measurements from Photogrammetry

Publicly available data related to the standard deviation of linear measurements from photogrammetry models is limited. Existing studies typically look at the accuracy of stockpile volumes, and does not include data specific to linear, point-to-point measurements. This makes it incredibly difficult to understand the margin of error one can expect from distance and area measurements.

In addition, canonical research on photogrammetric accuracy focuses on the use of GCP checkpoints. This means the accuracy is measured as a difference between the geographic position of a checkpoint as recorded by precision GPS, and the theoretical position of that checkpoint as calculated by the photogrammetry software. This method has been favored because it is the best way to isolate experimental variables, and considered to be the most scientifically rigorous. However, because a checkpoint's accuracy can only apply to a single point in space, the data does a poor job of evaluating the accuracy of linear measurements.

Guidelines for Producing Accurate Aerial Maps with Drones

To date, there are few resources that provide guidelines regarding the capture and processing of aerial data for commercial use. Those that do exist do not provide hard data to back up suggestions, which leaves mapping professionals with little evidence to guide data capture methods.

Methodology

Establishing a Ground Control System

To test the accuracy of two-dimensional measurements, DroneDeploy established a ground control system on the roof of its 1045 Bryant Street offices. This is shown in Figure 2. In addition to ground control points, this control system defined control distances with known lengths. These control distances could then be compared with theoretical measurements made with photogrammetry software.

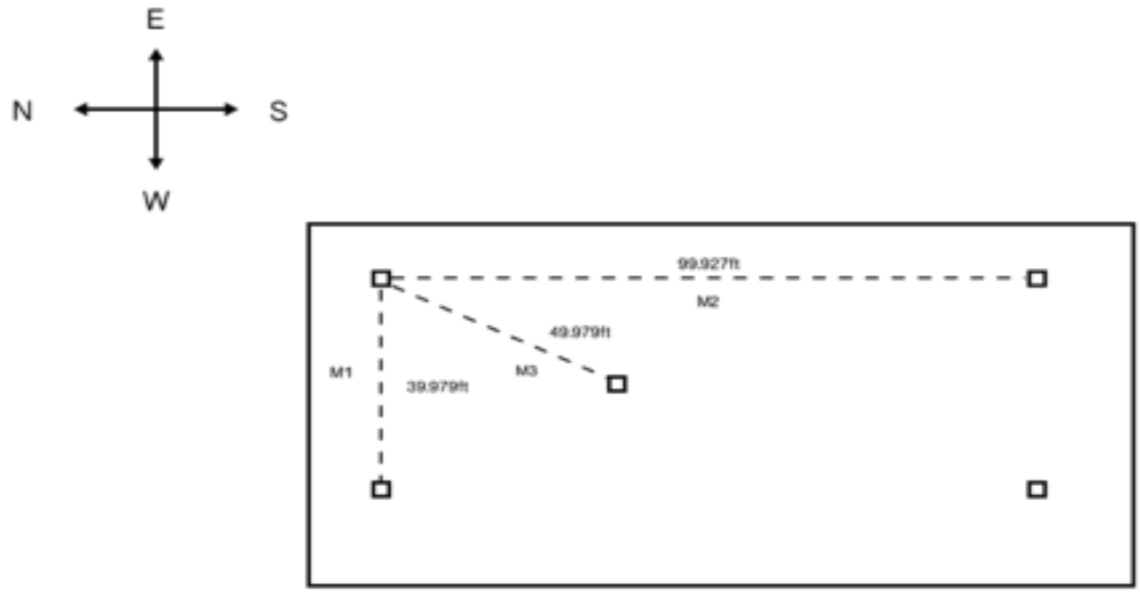

Figure 2. Ground Control System

The ground control system used three 1’x1’ checkered markers that were placed in a large right angled “L” shape along the building's primary axis, with a fourth marker was added as a length that bisects the “L” axis. The control distances between each marker were measured manually using a metal tape measure and checked with a Leica Laser Distance Meter.

Collecting Aerial Data

Aerial data was then collected over more than 80 individual flights using DJI drones and the DroneDeploy mobile application. A total of 4 flights were flown at 66 ft., 100 ft., 200 ft., and 400 ft. above the surface of the roof using each DJI drone model, and then identically processed with the DroneDeploy map engine. Slight variations in lighting, flight path, and altitude were included to simulate real world variation in collected mapping data.

Capturing Ground Control Point Data

To collect the ground control point data, 5 additional targets measuring 3”x3” were placed on the roof. The geographic locations of the center of these larger targets were then recorded with an Emlid Reach RS and Trimble Catalyst. These global navigation satellite system (GNSS) receivers can be seen in Figures 3 and 4.

A processed aerial map of the ground control system setup can be seen in Figure 5. Once the ground station was set up, a DJI Phantom 4 Pro was used to map the roof once more at elevations of 66 ft., 100 ft., 200 ft., and 400 ft.

To better understand the standard deviation and average margin of error, a statistical sample was taken using the Phantom 4 Pro. Flying identical mission plans with GCPs at an elevation of 66 ft., a total of 6 flights were completed. Similarly, a final dataset was created without GCPs by flying the Phantom 4 Pro at 66 ft. an additional 10 times. This method was adopted to approximate the variation present in linear measurement accuracy when mapping one location under the same conditions.

Figure 3. Emil Reach RS

Figure 4. Trimble Catalyst

Figure 5. Aerial View of Ground Control System

Key Findings

On Average, Linear Measurements are Accurate to Within 1.1%

When comparing the data collected across all the DJI drone models included in the study, the average margin of error for all flights was found to be 1.1%. By this we mean the value of the average measurement error was 1.1% of the value of the control length. Thus, when measuring a 100ft length the average error would be 1.1 ft. These results can be found in Table 2.

Flight Altitude (ft.)	Measurement 1 (40ft) Error (ft.)	Measurement 3 (50ft) Error (ft.)	Measurement 2 (100ft) Error (ft.)
66	0.25	0.27	0.54
100	0.35	0.39	0.85
200	0.56	0.79	1.34
400	0.67	0.88	1.44
Avg. Measurement Error (ft.)	0.45	0.57	1.04
Avg. Measurement Error (%)	1.12%	1.14%	1.04%

Table 2. Margin of Error Without GCPs

Higher Resolution Cameras Reduced Average Measurement Error by 0.33%

The data shows a clear correlation between higher resolution imagery and highly accurate maps. For example, the maps produced with the 12MP P3P camera yielded an average margin of error of 0.72 ft. across measurements taken, whereas the maps produced with the 20MP P4P camera yielded an average margin of error of 0.46 ft. By comparing the average margins of error for each control length as a percentage, it was found that the average measurement error for 20MP camera was 0.33% less than the 12MP camera. This data can be seen in Table 3. While 0.33% my not seem significant, remember that would be a 0.33 ft. (~4 in.) reduction of error for a 100 ft. measurement.

The average measurement errors between the 12MP maps and 20MP maps showed that error would increase proportionally to camera resolution with a correlation coefficient of 0.33. Between 12MP and 16MP maps, this correlation coefficient was calculated at 0.56.

	Measurement 1 (40ft) Error (ft.)		Measurement 2 (100ft) Error (ft.)		Measurement 3 (50ft) Error (ft.)	
Flight Altitude (ft.)	**P3P (12MP)**	**P4P (20MP)**	**P3P (12MP)**	**P4P (20MP)**	**P3P (12MP)**	**P4P (20MP)**
66	0.34	0.19	0.73	0.46	0.34	0.245
100	0.39	0.30	0.88	0.84	0.41	0.31
150	0.47	0.60	1.09	1.52	0.38	0.64
200	0.32	0.89	0.64	2.18	0.52	1.04
300	1.55	0.12	3.58	0.36	1.94	0.06
400	0.92	0.33	1.99	0.68	1.13	0.41
Avg. Measurement Error (ft.)	0.49	0.40	1.06	0.49	0.60	0.49
Avg. Measurement Error (%)	1.22%	1.00%	1.06%	0.49%	1.20%	0.98%

Table 3. Correlation Between Resolution and Measurement Accuracy

The average measurement errors between the 12MP maps and 20MP maps showed that error would increase proportionally to camera resolution with a correlation coefficient of 0.33. Between 12MP and 16MP maps, this correlation coefficient was calculated at 0.56.

Flying Low Improved Measurement Accuracy by 0.35%

The data suggests that flight plans conducted with lower altitudes will produce maps with higher accuracy than those flying at higher elevations. The average measurement errors showed that error would increase proportionally to flight altitude with an average correlation coefficient of 0.42. This correlation is visualized below in Chart 1 and Table 4.

There was a 0.35% improvement in measurement accuracy for maps flown at 66 ft. elevation compared with those flown at 100, 200, or 400 feet of elevation.

Height Correlation Factor	Measurement 1 (40 ft.)	Measurement 2 (100 ft.)	Measurement 3 (50 ft.)	Average
Phantom 4 Pro	0.466	0.453	0.419	0.45
Inspire 1 Pro (X5)	0.355	0.334	0.564	0.42
Inspire 1 (X3)	0.548	0.512	0.807	0.62
Phantom 3 Pro	0.355	0.295	0.378	0.34
Total				0.46

Table 4. Flight Altitude to Measurement Error Correlation Coefficients

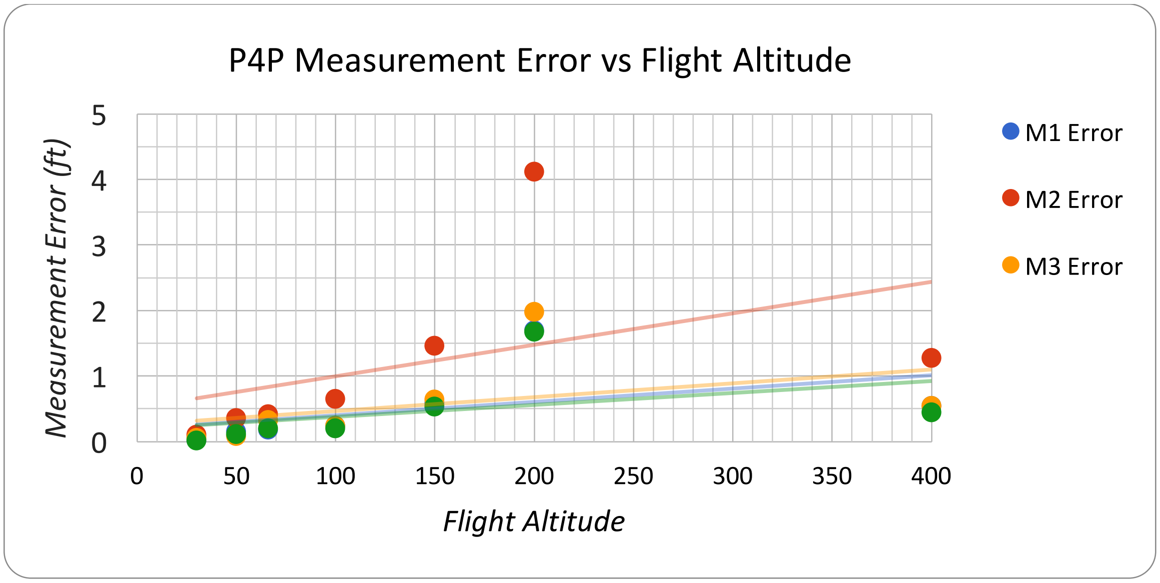

Chart 1. Phantom 4 Pro Measurement Error vs. Flight Altitude

Together, Camera Resolution and Altitude Halved Average Measurement Error

When flying at lower altitudes and with a high-resolution camera – the average margin of error was reduced to 0.64%. This is nearly half the average margin of error for all drones at all altitudes. These results can be found in Table 5.

P4P Flight Number	**Measurement 1 (40ft) Error (ft.)**	**Measurement 3 (50ft) Error (ft.)**	**Measurement 2 (100ft) Error (ft.)**
1	0.20	0.47	0.14
2	0.34	0.90	0.35
3	0.42	1.15	0.45
4	0.49	1.24	0.50
5	0.07	0.21	0.02
6	0.13	0.32	0.26
7	0.14	0.24	0.22
8	0.52	1.32	0.56
9	0.04	0.09	0.07
10	0.25	0.63	0.22
Average (ft.)	0.26	0.28	0.66
Average (%)	0.65%	0.56%	0.66%

Table 5. Margin of Error Without GCPs

Visualizing Map Resolution by Altitude

There was a significant difference in map resolution when flying at higher altitudes. This effect of altitude on map resolution made it difficult to mark the center of each ground control point when processing map data in DroneDeploy. For an example of the effect altitude has on image resolution see Figure 7.

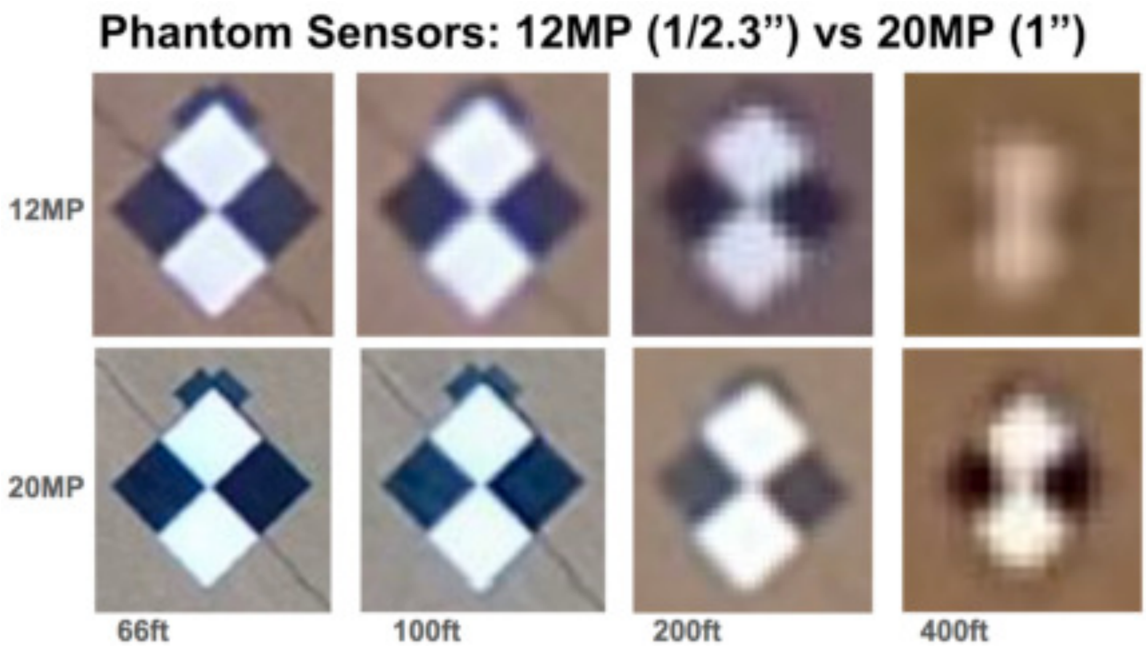

Figure 7. Map Resolution Visualized by Altitude

Ground Control Points Improved Mapping Accuracy 10x

Across the 9 maps processed with GCPs, the average measurement error was reduced to 0.04 ft. (0.5 inches). Unlike the non-GCP maps, the average error was not dependent on the magnitude of the control length. The 100 ft. control length, which always produced the largest margin of error when measured on the non-GCP maps, was the most accurate with an average error of 0.01 ft. (0.12 inches. These small errors were also incredibly consistent and had very little variance. The average standard deviation (σ_x) of measurement errors on GCP maps was $\sigma_x = 0.02$, which was 10x smaller than non-GCP maps as shown in Chart 2.

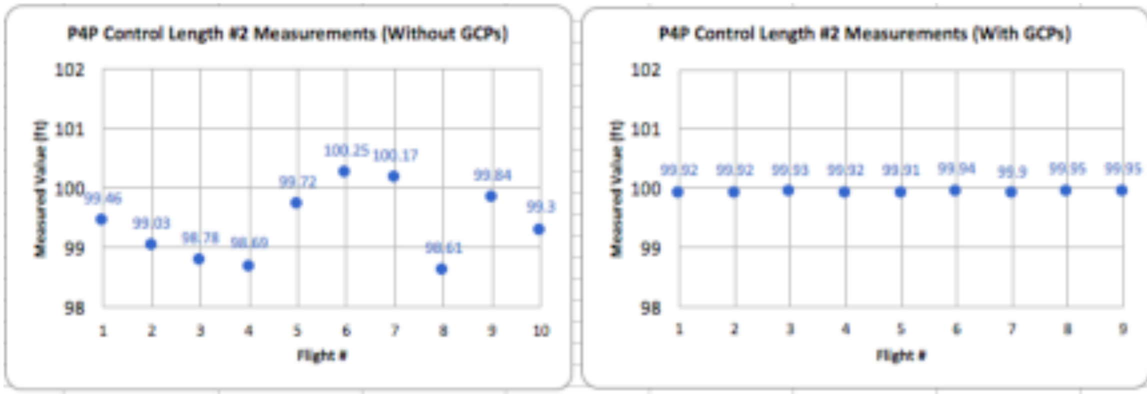

Chart 2. Phantom 4 Pro Map Measurement Variance

Conclusion

Use High Resolution Cameras for Increased Measurement Accuracy

DroneDeploy’s data shows that using a camera with at least 20MP reduces the average margin of error in linear measurements to 0.64%. The data collected using the DJI Phantom 4 Pro and 20MP camera with mechanical shutter provided the most accurate data and measurement results compared with lower resolution cameras such as those used with the DJI Mavic Pro or Inspire Series. DroneDeploy suggests customers seeking to make the most accurate maps for measuring distances point-to-point use the Phantom 4 Pro.

Fly Missions at Low Altitude for Higher Measurement Accuracy

DroneDeploy’s data suggests that creating flight plans with lower elevations can reduce the margin of error significantly. Exact reductions in error are dependent upon the camera used. See Table 4 for a comparison of this reduction in both 12MP and 20MP DJI cameras. DroneDeploy recommends that pilots create flight plans that balance the needs of the mission against the flight settings. Fly lower, with higher overlap and sidelap, if one intends to make accurate linear measurements using the drone-generated orthomosaic map. This will of course result in a larger image payload to be processed within the DroneDeploy map engine. This increase in images will also have an increase on upload and processing time.

Ground Control Points Produce the Most Consistent, Accurate Results

DroneDeploy's study shows that there can be a wide range of error present across datasets collected using DJI drone models and cameras. The average linear measurement margin of error without the use of ground control points was 1.1% of the control length, however, individual error values fell anywhere in the range of 0.01 ft. to 6.99 ft. If a project requires highly consistent rates of accuracy, or should mission-critical determinations need to be made from the dataset, then ground control points should be used. This study found that processing with ground control points reduced the average measurement error to 0.5 inches, a near 10x improvement, for all the control lengths. The measurement errors for GCP maps also showed a similar 10x reduction in the standard deviation of the error, meaning not only is GCP data more accurate, it is more consistent and reliable for applications that require higher accuracy.

Altitude Matters When Mapping with Ground Control Points

As previously mentioned, image resolution will be affected by altitude. This will make it difficult to mark the center of your ground control point marker when processing the map in DroneDeploy. Accuracy will not matter if you are unable to precisely identify the center of your target. Pilots should be sure to take this into consideration and adjust flight altitude to achieve a desired resolution that will allow them to properly and confidently identify the GCP target within their processed drone map.

Additional DroneDeploy Resources

A Guide to Using Ground Control Points with Drone Mapping Software

https://blog.dronedeploy.com/what-are-ground-control-points-gcps-and-how-do-i-use-them-4f4c3771fd0b

Deciding If Your Drone Mapping Project Needs GCPs

https://blog.dronedeploy.com/when-to-use-ground-control-points-2d404d9f5b15

Capturing Ground Control Points (GCPs)

https://support.dronedeploy.com/docs/working-gcp-step-by-step

GCP Request Checklist

https://support.dronedeploy.com/docs/gcp-request-checklist

DroneDeploy In-Browser GCP Tagging Workflow

https://support.dronedeploy.com/docs/in-browser-gcp-tagging

Acknowledgements

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DroneDeploy would also like to thank Trimble for including us in the Catalyst beta program. For more information about the Trimble Catalyst visit: https://catalyst.trimble.com/

Appendix

View Complete Dataset and Explore Completed Maps and Measurements:
https://www.dropbox.com/s/wqqxhe6od798u4j/Linear%20Measurement%20Accuracy%20of%20DJI%20Drone%20Platforms%20and%20Cloud-Based%20Photogrammetry%20Appendix%20A%2C%20Dataset.xlsx?dl=0