DroneDeploy

Measurement Accuracy of the DJI Phantom 4 RTK & Photogrammetry

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Published in Partnership with

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Acronyms

DJI GS Pro - DJI Ground Station Pro Mobile App

DJI GS RTK - DJI Ground Station RTK Mobile App

GCP - Ground Control Point

GNSS - Global Navigation Satellite Systems

GSD - Ground Sampling Distance

NTRIP - Network Transport of RTCM via Internet Protocol

RTCM - Radio Technical Commission for Maritime Services

P4 RTK - Phantom 4 RTK Drone

P4 Pro - Phantom 4 Pro Drone

PPK - Post Processed Kinematics

RTK - Real Time Kinematics

VRS - Virtual Reference System

Abstract

Over the past few years, unmanned aerial vehicles (UAVs), commonly known as drones, have increasingly become a popular tool for aerial data collection in construction, surveying, mining, and insurance. Utilizing photogrammetry, these industries capture aerial imagery and generate valuable insights from large data sets—making it possible to see and measure the changes occurring over time on job sites, mines, and properties.

Photogrammetry is not a new science and has been used for topographic mapping, architecture, and engineering long before the advent of drones. But the rise of computer vision-driven photogrammetry in recent years has paralleled the development of accessible commercial drone hardware and software. The simplicity and automation of today's solutions allow professionals to integrate these flying robots into existing workflows to map huge swaths of land and generate high-resolution 3D models. This data makes it possible to analyze the world around us more accurately and quickly than traditional measurement methods, such as ground surveys and manual measurements. In our last white paper, we showed drones can deliver accuracy within 1% of real world measurements when using Ground Control Points (GCPs).

GCPs are defined points on the surface of the earth that have a known geo-referenced location. By using GCPs in conjunction with aerial photogrammetric data, you're able to achieve centimeter level accuracy by "pinning" those points on our aerial map. While accurate, GCPs tend to be a time-consuming process and often require placement throughout the entire duration of a project. When GPS was first used for surveying back in the 1980s, the only way to obtain sub-centimeter positioning with GPS was via post-processing with GCPs, which could take entire days to accurately capture. In the early 1990s, Real Time Kinematic technology (RTK) was introduced, and allowed surveyors to obtain centimeter-level positioning in real-time, with no post-processing required.

In this study, DroneDeploy investigates ways to validate and improve the accuracy of photogrammetric maps with DJI's Phantom 4 RTK (P4 RTK), a drone that applies RTK technology to aerial imagery. To test the accuracy of the P4 RTK, DroneDeploy created a control point system for a rooftop building survey. Then, 32 flights were logged — each exploring the effect of flight altitude, overlap, and number of images, on the resulting map accuracy once those images have been processed through DroneDeploy's Map Engine. These data sets were then used to calculate both the horizontal and vertical accuracy of the measured points, along with the accuracy of linear measurements.

DroneDeploy found that P4 RTK control distances were within 0.27% of GPS Unit measurements, P4 RTK control distances were within 0.1% of P4 Pro with GCP measurements, P4 RTK delivered 2 cm relative vertical accuracy and 1.2 cm relative horizontal accuracy, and that 2D and 3D Flights did not significantly affect measurement accuracy.

01

Introduction

Goals of this Study

imilar to our last white paper on drone cccuracy and cloud-based photogrammetry, when you're analyzing drone data, speed and accuracy are critical to managing operations on a construction site, monitoring yields on a farm, or inspecting a roof for damage.

The primary goal of this study is to prove the elevation and linear measurement accuracy of the P4 RTK against traditional GPS based capture methods. using a ground-based GNSS receiver. The results give insight into the accuracy you can expect from each method. The resulting data set can also be used to determine whether a drone mapping mission with the P4 RTK and DroneDeploy can achieve the accuracy requirements of your project.

We will not be demonstrating the accuracy of using drone based imagery in conjunction with a photogrammetric map and GCPs, as those results can be found in the Drone Accuracy and Cloud-based Photogrammetry whitepaper.

Best Practices for Accurate Data Collection

In this study, we will also explore best practices for capturing highly-accurate data with the P4 RTK. This will include determining the mission type that will yield the best results, either 2D Photogrammetry or 3D Photogrammetry flight modes.

Drone Models Used in this Study

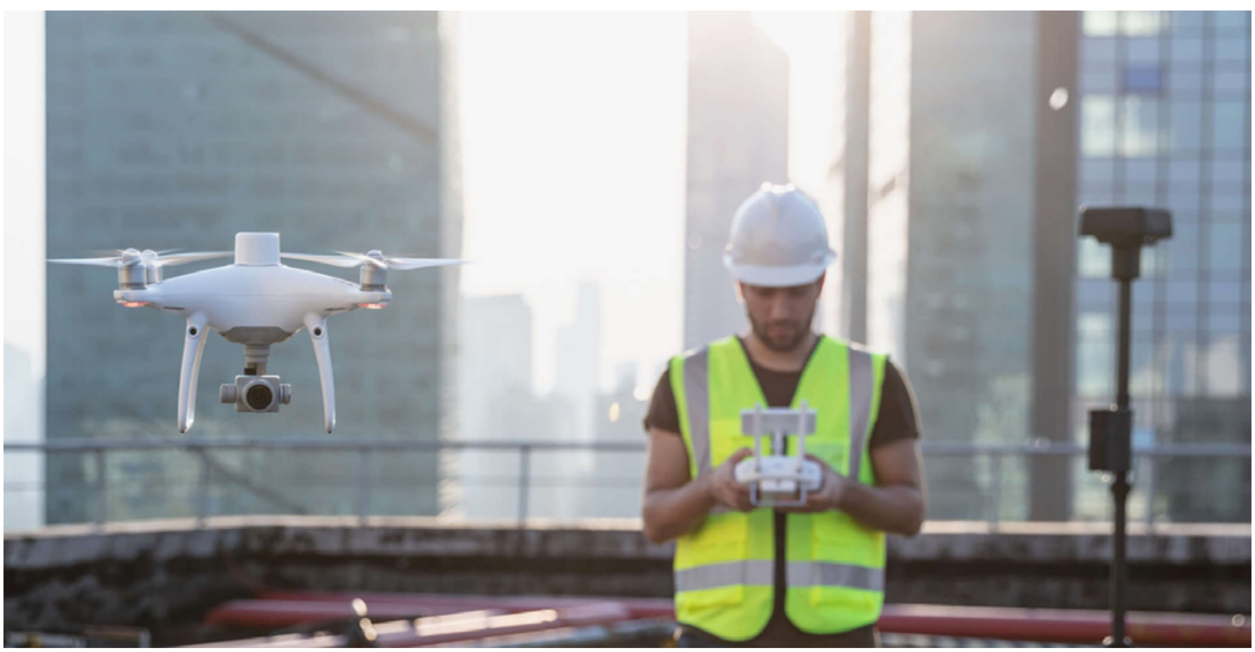
The primary drone model used in this study is the DJI Phantom 4 RTK, which was released by DJI in October 2018. The drone was designed to use real-time kinematic processing to produce highly accurate aerial maps. In addition to the RTK unit, the P4 RTK also uses a redundant GNSS module that provides additional flight stability when flying in dense regions with poor RTK signal. DJI claims 1 centimeter RTK horizontal positioning accuracy, and 1.5 centimeter RTK vertical positioning accuracy. In terms of absolute measurements on photogrammetric models, DJI claims 5 centimeter accuracy when flying at 100 meters with 2.7 centimeter GSD. This drone can be seen in Figure 1 shown below.

Figure 1. DJI Phantom 4 RTK (P4 RTK)

The RTK module is integrated directly with the Phantom 4 to provide centimeter-level accuracy for stable flight and accurately georeferenced imagery. A new TimeSync system was added to continually align the flight controller, camera, and RTK module—ensuring each photo uses the most accurate metadata and fixes the positioning data to the center of the CMOS sensor. This RTK receiver can be seen in Figure 2 below. The P4 RTK also has the ability to connect to the D-RTK 2 Mobile Station, NTRIP (Network Transport of RTCM via Internet Protocol), or store the satellite observation data to be used for Post Processed Kinematics (PPK). The D-RTK 2 Mobile Station was not measured in this study, instead the NTRIP methods was used and is described in detail throughout this white paper.

Figure 1. DJI Phantom 4 RTK (P4 RTK)

The DJI Phantom 4 Pro will also be used in conjunction with GCPs to serve as the control data. This study uses DJI models because they are the largest commercial drone hardware provider in the world and are used by industry professionals in construction, mining, surveying, and insurance. The Phantom 4 Pro was shown in the previous study to produce the most accurate photogrammetric maps at the time of writing, as compared to other DJI models. It is the most popular drone used by DroneDeploy's customers, with over 23,000 flights each month, and will provide DroneDeploy's customer base with the insight into the accuracy of this new hardware solution by DJI.



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Background

Linear Measurement Accuracy of the Phantom 4 Pro

Our prior study looked at the linear measurement accuracy using the DJI Phantom 4 Pro in conjunction with GCPs. The Phantom 4 RTK drone is part of the Phantom 4 series of drones and utilizes the same camera found in the Phantom 4 Pro. In that study, we demonstrated that relative linear measurements were accurate to within 1.1% of manual measurements made on the ground. The average measurement errors showed that margin of error would increase proportionally to flight altitude with an average correlation coefficient of 0.42. 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. Much of that can be attributed to the quality of the images, and allowing a human operator to identify the center of those GCPS, which can be difficult on lower resolution maps.

We 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 therefore reliable for applications where a higher degree of accuracy is needed.

Real-Time Kinematic (RTK) and Post-Processed Kinematic (PPK) Procedures

Kinematic is a common term used in traditional GPS surveying methods where the receivers are in motion. To process RTK data, you will need both an RTK Base Station and a RTK Rover, in this case, the Phantom 4 RTK. For relative positioning, the common method used in surveying is the “Stop and Go” technique. RTK processing on the other hand does not require post processing to obtain accurate positioning. A radio at the reference receiver —either a local base station or a network base station— broadcasts its position to the rover in real time. This allows for in-field surveying and eliminates the need to check measurement quality during post processing. A diagram of the RTK workflow can be seen in Figure 3.

PPK surveys are similar to RTK surveys, but the positions are not corrected in real time. It usually involves placing a stationary base station over a known control point, or a monument to allow for geolocation. GPS data is then simultaneously collected by the base station and the drone as it flies. That data is then downloaded from the base station, and the rover (drone), and post processed using a GPS software. These images can then be uploaded to DroneDeploy’s Map Engine for processing.

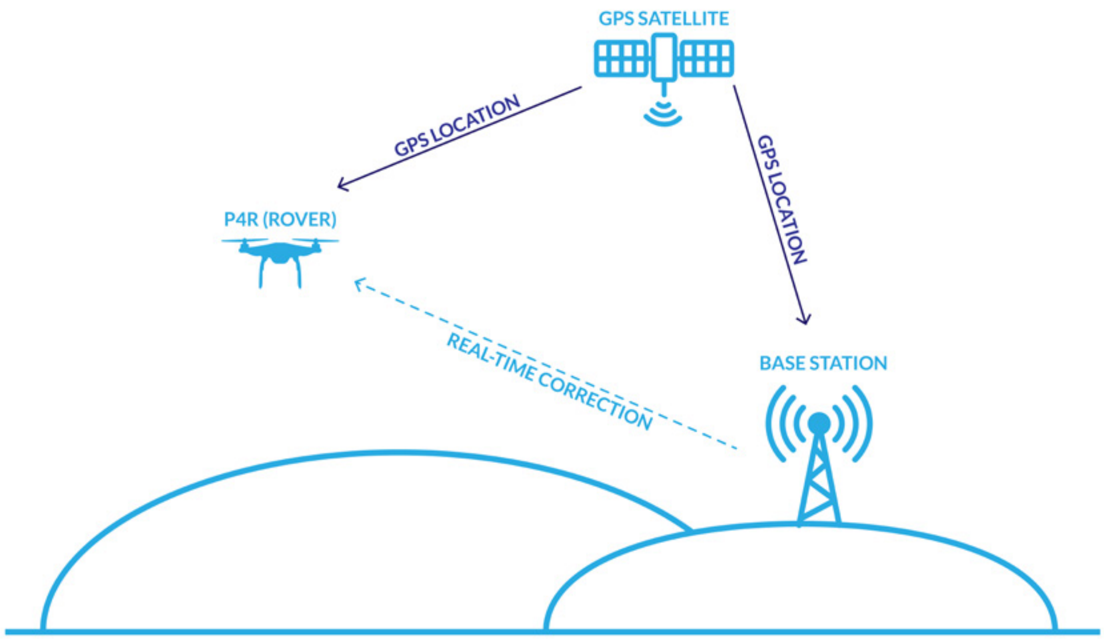

Figure 3. RTK Workflow with the P4 RTK

When choosing between RTK or PPK methods, you need to make a choice between productivity and accuracy of the resulting imagery. The RTK workflow can be a very quick way to obtain accurate imagery but relies on a real-time connection to produce accurate maps. A PPK solution takes more time to set up but relies on its signal backup data to ensure positional accuracy of the flight.

Guidelines for Producing Accurate Drone Maps with the Phantom 4 RTK

Our prior study showed, as expected, that flying lower produces higher quality maps, and that the higher resolution camera onboard the Phantom 4 series of drones provides better maps than its predecessors. We will follow those same guidelines for flying maps using the P4 RTK to provide consistency between the RTK maps and the P4 Pro maps.

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Methodology

Establishing a Data Validation Method using GCPs and Control Points

To test the accuracy of the Phantom 4 RTK, DroneDeploy set up a control point system on the same test site used in the prior study. The checkpoints, GCPs, control distances, and respective layout are shown in Figure 4 below.

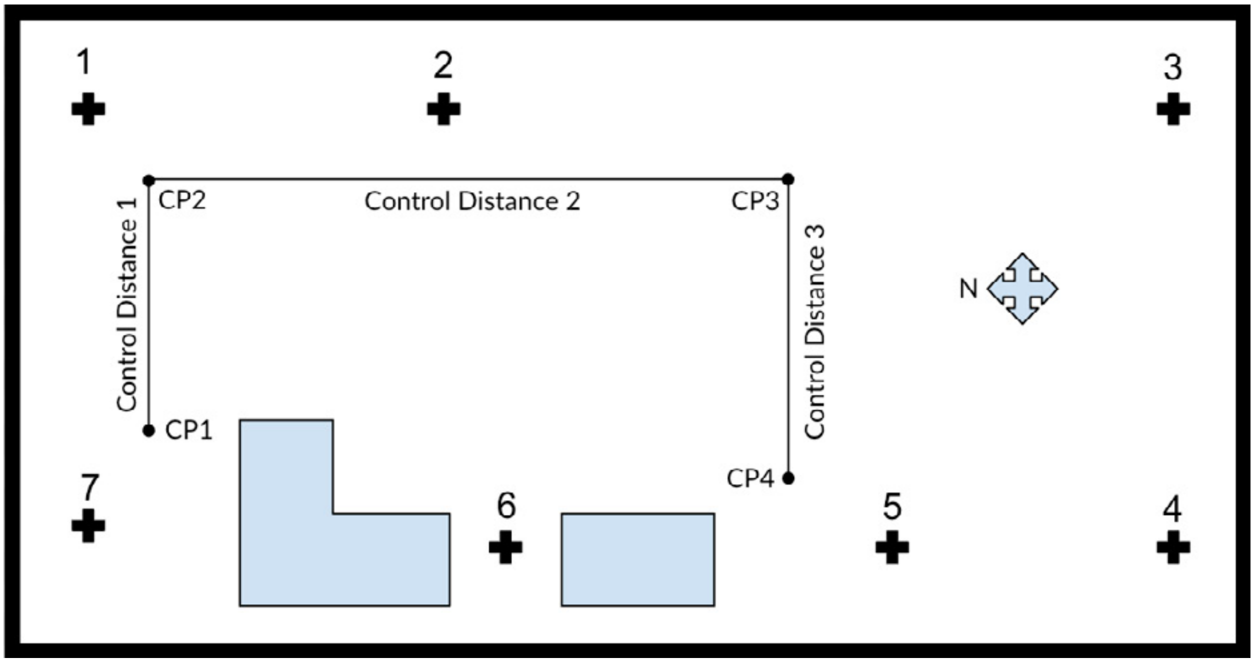

Figure 4. Control Point System

The system was made up of 7 different, 1' x 1' GCPs placed on our test site. These points were placed at varying elevations, latitudes, and longitudes on the surface to be able to best capture differing scenarios. Additionally, 4 checkpoints were placed on the roof and the distances between each were measured with a tape measure to establish the length between the points. They were then tagged and measured using a Trimble RTX GPS unit to identify the lat, long, and elevation of each of the points.. These control distances demonstrate the variation in latitude, longitude, and elevation between the Phantom 4 Pro and P4 RTK flights.

Capturing Aerial Data

To capture the aerial data, DroneDeploy flew 30+ individual flights using the DJI Phantom 4 RTK and DJI GS RTK App for the RTK flights, and the Phantom 4 Pro V2.0 and DJI GS Pro app for the P4 Pro with GCP flights. SmartNet, a third-party corrections service was used for the RTK controller in conjunction with a mobile hotspot. SmartNet allows for high-precision, high-availability network RTK corrections for any application, using any constellation, while at the same time being open for anyone to use. SmartNet allows for centimeter-level accuracies tied to a common datum.

Figure 5. Processed Orthomosaic Map

A total of 20 flights were flown with the P4 RTK at 100 feet above the surface of the roof, in both 2D and 3D photogrammetry modes and then processed with DroneDeploy's Map Engine. Similarly, 12 flights were flown with the Phantom 4 Pro and processed with GCPs with DroneDeploy's Map Engine to serve as the control to compare the results against. One of the processed aerial maps with checkpoints and GCPs can be seen in Figure 5 above. Slight variations in flight planning, lighting, and altitude were introduced to simulate a real-world environment when collecting this data.

Capturing Ground Control Point Data for Control

To capture the GCPs for the control, DroneDeploy tagged the geographic center of the targets placed on the roof with a Trimble Catalyst. The targeted points had a horizontal standard deviation of 0.24 cm and a vertical standard deviation of 0.49 cm across the 7 ground control points and checkpoints tagged on the test site.

These points were also used to serve as control points when measuring the accuracy of the P4 RTK against GCP measurements. The Trimble Catalyst, shown in Figure 6 below, was chosen due to it's simplicity, low cost, and highly-accurate GNSS performance. In an independent study run by Geo Job UAV in early 2018, they deduced, "Catalyst coordinates were within .25-inch to less than 1-inch of the results from the surveyor". With it's integration with the Trimble UAV Ground Control software, it also provided a simple way to capture control point data to be used with UAV solutions.

Figure 6. Trimble Catalyst

Trimble Catalyst is an RTK GNSS positioning 'as a service', and can be used with any modern mainstream Android smartphone. The hardware setup consists of any modern Android device, the Trimble Catalyst DA1 antenna, and a standard survey pole. Your smartphone is used in place of a traditional data logger and is connected to the antenna via the supplied USB cable.

Rather than using a 'hardware' GPS chip, Catalyst uses an entirely 'software-defined' GNSS receiver; positions are calculated in software, using your smartphone's processor—reducing the size, weight, and battery power demands of the overall system. Catalyst operates at 2-3m without any recurring account cost, but accuracies down to 1-2 cm are readily achievable with a month-by-month subscription (which unlocks the receiver's high-accuracy modes, and bundles access to Trimble's localized VRS Now and global Trimble RTX correction services at no additional cost). To control the receiver, two apps must be installed from the Google Play store, Trimble Mobile Manager and any one of the purpose-built applications on offer, in our case, the Trimble UAV Ground Control software.

Due to its simplicity, high degree of accuracy, and acceptance amongst DroneDeploy's customers base, we were able to use the Trimble Catalyst to confidently ensure the validation accuracy against the P4 RTK. We would recommend using a high accuracy GNSS receiver, such as Catalyst, when processing maps with DroneDeploy to verify the accuracy of the maps on your jobsite for auditing and assurance.

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Key Findings

P4 RTK Delivered 2 cm Relative Vertical Accuracy and 1.2 cm Relative Horizontal Accuracy

Each of the 4 checkpoints were tagged and measured with the Trimble GPS unit. Table 3 below shows the vertical accuracy of the checkpoints, both in the RTK processed map and the P4 Pro with GCPs map. The GPS unit error is shown for understanding the vertical measurement error of the Trimble Catalyst. About 30 measurements were captured and averaged for each GCP and checkpoint.

From those measurements, we get about 3.3cm relative vertical accuracy and 2.01cm relative horizontal accuracy. The average relative vertical accuracy of all of the checkpoints in the P4 RTK map was 2.00 cm. The average relative vertical accuracy of the P4 Pro with GCPs, for comparison came out to 1.95 cm.

	P4 RTK (cm)	P4 PRO w/ GCP (cm)	GPS Unit
Vertical Accuracy (cm)	2.00	1.95	2.26 (0.24%)
Horizontal Accuracy (cm)	1.20	.90	0.59 (0.03%)

Table 3. Comparing P4 RTK vertical accuracy against P4 Pro with GCP measurements

With the P4 RTK, we achieved 1.20 cm relative horizontal accuracy. With the P4 Pro and GCPs, we achieved 0.90 cm relative horizontal accuracy. In this study, we have shown that the P4 RTK can achieve 2.00 cm relative vertical accuracy, and 1.20 cm relative horizontal accuracy when flown at 100 ft (33m). It's also important to note that the accuracy measurements for the P4 RTK were taken using DroneDeploy's annotation and measurement tools. The GSD for the resulting maps average 0.4in/px.

Why is this Important?

Determining accurate elevations is an essential part of many civil construction projects like road, bridges, and highway projects. Grade lines, drainage structures, and other highway features are designed with existing, known base planes, and final elevations, or design plans. Preliminary and final cross sections also determine volumetric quantities. Additionally, accurate elevations are critical in ensuring the reliability of photogrammetric mapping and orthophoto products within DroneDeploy, and other photogrammetric software.

Due to its importance in all other phases of the project development, vertical measurements are established at a control point, known as GCPs. Due to the sizeable downstream effect of inaccurate vertical measurements, this is a critical component of pre-construction, and reducing the resulting error is of utmost importance.

P4 RTK Control Distances Within 0.1% of P4 Pro with GCP Measurements

In the Linear Measurement Accuracy of DJI Drone Platforms and Photogrammetry study, we demonstrated that using a Phantom 4 Pro with GCPs would produce a margin of error of about 0.64%. Using a Phantom 4 RTK, we were able to produce a margin of error of about 0.27% when compared to “real-world” measurements. In Table 2, we compare the accuracy of the P4 RTK against the P4 Pro. On average, P4 RTK measurements are within 1.09 cm, or 0.10%, of P4 Pro measurements processed with GCPs. These results show that using a Phantom 4 RTK drone, a user can expect—on average—1.09 cm accuracy on RTK processed maps in DroneDeploy, when compared to similar maps flown with the Phantom 4 Pro, and processed with GCPs.

	P4 Pro w/ GCPs (cm)	P4 RTK (cm)	**Difference (cm)**
Distance 1	924.5	922.2	2.26 (0.24%)
Distance 2	1912.9	1912.3	0.59 (0.03%)
Distance 3	1220.5	1221.0	0.43 (0.04%)
Average			1.09 (0.10%)

Table 2. Comparing P4 RTK vs. P4 Pro w/GCP Control Distance Measurements

Why is this Important?

Linear measurement accuracy is an important metric to consider because of its real world applications. While it can be important to look at the horizontal and vertical accuracy of a single point, many civil construction projects look at grade lines, drainage along a road, volumetrics of stockpiles, or material area—all of which rely on the accuracy of point-to-point measurements.

This process involves understanding the change in accuracy when measuring the variation between points. For example, a ±2 cm horizontal or vertical accuracy could equate to ±4 cm linear measurement accuracy between 2 points. This provides a more tangible understanding of how accuracy could affect measurements of a road, bridge, highway, or other civil construction project.

P4 RTK Control Distances Within 0.27% of Trimble Catalyst Measurements

Once the P4 RTK maps were processed within DroneDeploy, the control distances were tagged and measured across all of the maps using DroneDeploy’s measurement tools. The comparison between the P4 RTK map measurements and the real-world measurements can be seen in Table 1 below. The average error for the P4 RTK maps came out to 3.65 cm, or about 0.27% of real-world measurements. For comparison, using GCPs a user can expect 3 cm accuracy, and using a GPS unit, like a Trimble Catalyst, a user can expect 3 cm accuracy.

Looking at solely the XY accuracy of the control points, the P4 RTK delivers 1.2cm relative horizontal accuracy. These results show that using a Phantom 4 RTK drone, a user can expect, on average, 3.65 cm linear measurement accuracy on RTK processed maps in DroneDeploy. Note: The Real World measurements were taken using a tape measure.

	P4P w/ GCPs (cm)	P4 RTK (cm)	Difference (cm)
Distance 1	924.5	922.2	2.34 (0.25%)
Distance 2	1917.7	1912.3	5.33 (0.28%)
Distance 3	1224.3	1221.0	3.29 (0.27%)
Average			3.65 (0.27%)

Table 1. Comparing P4 RTK vs. Real World Control Distance Measure-

2D and 3D Flights Did Not Significantly Affect Measurement Accuracy

A total of five 2D, and five 3D Photogrammetry flights were flown using the DJI GSR App with the P4 RTK. The results of this study can be seen in Table 4 below. Average linear measurement error for the 2D flights was about 3.57 cm or 0.26%. Average linear measurement error for the 3D flights was about 3.73 cm or 0.28%. Average linear measurement error for P4 Pro flights was about 3.53 cm or 0.26%. At 0.16 cm margin of error between the 2D and 3D flights, we do not have a statistically significant variation in linear measurement accuracy. When flying the P4 RTK for high accuracy missions, choosing 2D or 3D would be dependent on the user's needs, flying 2D for relatively flat terrain, and flying 3D for structures, buildings, or other tall objects.

	Difference (cm)
Avg. P4 RTK 2D Error	3.57 (0.26%)
Avg. P4 RTK 3D Error	3.73 (0.28%)
Avg. P4 Pro w/ GCP Error	3.53 (0.26%)

Table 3. Comparing P4 RTK 2D photogrammetry against P4 RTK 3D photogrammetry flights.

05

Conclusion

Phantom 4 RTK Measurement Accuracy Can Meet Survey-Grade Requirements

The degree of accuracy that would be expected on certain projects is dependent on the final application and intended use of the survey data. The acceptable accuracy could be 30 cm or more away from the surveyed location.In certain projects, the maximum acceptable error could 5-7 cm or less. According to the USGS Global Navigation Satellite System Committee, it is the surveyor's responsibility to know the accuracy requirements of the survey and match this with the accuracy of his or her receiver in combination with the accuracy of the correction information received based on correction quality and location.

Today, companies can achieve sub 3 cm relative horizontal accuracy using traditional survey methods. These allow them to perform accurate surveys, bids, grading operations, and managing large-scale projects with ease. Most survey grade maps traditionally deliver sub 3 cm accuracy in the XY direction, and about 9 cm accuracy in the Z direction. In this, study, we've shown that the Phantom 4 RTK can deliver 2 cm relative vertical accuracy and 1.20 cm relative horizontal accuracy with maps processed on the DroneDeploy Map Engine (on average).

Based on these results, DroneDeploy recommends using the Phantom 4 RTK to create accurate maps for the measurement of point-to-point distances. Not only can you get accurate results, but in most cases using the Phantom 4 RTK to survey will reduce costs associated with traditional methods, including that spent on labor, hardware, and software. This also comes with the general benefits our customers achieve, such as greater productivity, faster time to insights, improved collaboration, and increased job site safety. However, the use of some ground control checkpoints (1-2 GCPs) is still recommended to ensure accuracy and provide accountability for any measurements.

Additional Resources

Determining the Accuracy of Your Map
https://support.dronedeploy.com/docs/accuracy

How the Phantom 4 RTK Improves the Accuracy of Your DroneDeploy Maps
https://blog.dronedeploy.com/the-future-of-drone-mapping-with-the-dji-phantom-4-rtk-ae484f4bd372

Deciding if Your Drone Mapping Project Needs High Accuracy Maps
https://blog.dronedeploy.com/when-to-use-ground-control-points-2d404d9f5b15

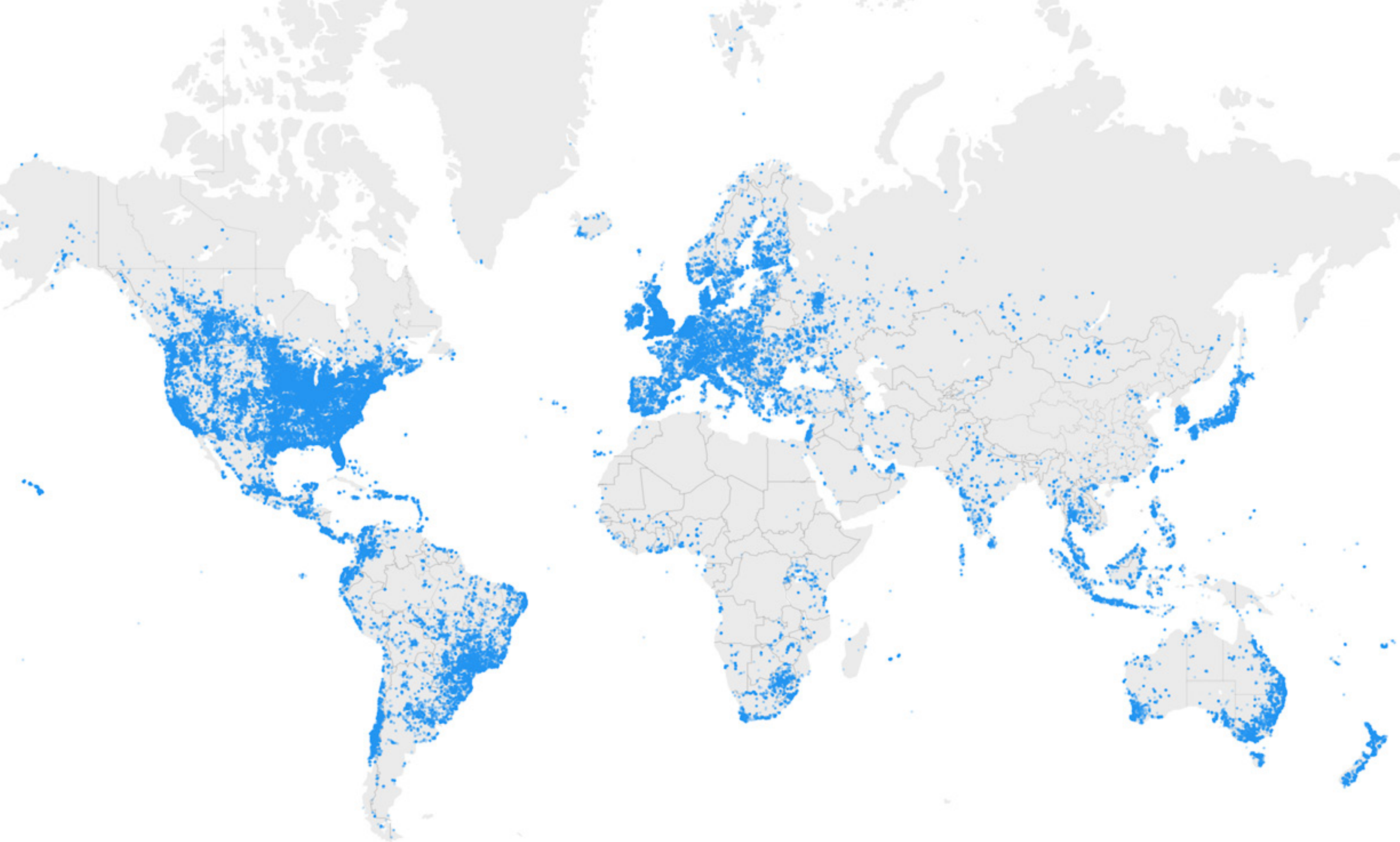
USGS Global Positioning Application and Practice Site
https://water.usgs.gov/osw/gps/

Virtual Reference Stations and How They Work
http://insidegnss.com/what-is-a-virtual-reference-station-and-how-does-it-work/

New Jersey State Surveying Measurements Resource
https://www.state.nj.us/transportation/eng/documents/survey/Chapter3.shtm#3.5

Appendix

View Completed Dataset Spreadsheet
https://docs.google.com/spreadsheets/d/1H7K7Czy-OZTMoch_T2jFqCuUsHVJ-Wrcpmag_JHNRos/edit#gid=336263784



Areas Mapped with DroneDeploy

7 Continents

180 Countries

40 Million Acres

About DroneDeploy

DroneDeploy is the leading cloud software platform for commercial drones, and is making the power of aerial data accessible and productive for everyone.

Trusted by leading brands globally, DroneDeploy is transforming the way businesses leverage drones and aerial data across industries, including agriculture, construction, mining, inspection and surveying. Simple by design, DroneDeploy enables professional-grade imagery and analysis, 3D modeling and more from any drone on any device.

DroneDeploy is located in the heart of San Francisco.
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